U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-260 137

MISSOURI RIVER INVESTIGATION. WINTER DISCHARGE NECESSARY FOR POLLUTION CONTROL BETWEEN FORT RANDALL NEAR YANKTON, SOUTH DAKOTA, AND THE MOUTH

PUBLIC HEALTH SERVICE
CINCINNATI, OHIO

PREPARED FOR
ARMY ENGINEER DISTRICT
OMAHA, NEBRASKA

FEBRUARY 1943

PB 260 137

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-260 137
4. Title and Subtitle Missouri River Investigation. Winter Discharge Necessary for Pollution Control Between Fort Randall, Near Yankton, S. D., and the Mouth			5. Report Date Feb 43 6.
7. Author(s) M. LeBosquet, Jr.			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Public Health Service, Cincinnati, Ohio.			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address Army Engineer District, Omaha, Nebr.			13. Type of Report & Period Covered 14.

15. Supplementary Notes
Sponsored in part by Army Engineer District, Omaha, Nebr.

16. Abstracts The final conclusions of a survey, made in 1942, of the Missouri River between Fort Randall, South Dakota, and the mouth to determine the minimum discharge required during the winter months to provide adequate flow for sanitation and water supply are presented. Previous investigations and the survey methods used are described; field, laboratory, and hydrometric data are presented; and ice cover and winter flow requirements are reported.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms
Missouri River
*Water pollution control
Silts
Water supply
Tables (data)
Water flow
Sewage treatment
Water pollution sampling

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 59
	20. Security Class (This Page UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

Federal Security Agency
U. S. PUBLIC HEALTH SERVICE
Office of Stream Sanitation
Cincinnati, Ohio
February, 1943

MISSOURI RIVER INVESTIGATION

Winter Discharge Necessary for Pollution Control Between Fort Randall, near Yankton, S. D., and the Mouth.

By

M. LeBosquet, Jr.
Senior Public Health Engineer
In Charge, Office of Stream Sanitation

Prepared by the U.S. Public Health Service at the request of the Chief of Engineers, U. S. Army, in co-operation with the District Engineer, United States Engineer Office, Omaha, Nebraska.

Contents

	Page
Introduction	1
Summary	1
Conclusions	2
Description	5
Previous Investigations	9
Survey Methods	11
Presentation of Field Data	13
Presentation of Laboratory Data	19
Hydrometric Data	24
Ice Cover	30
Winter Flow Requirements	32
Bibliography	36

List of Tables

1	Summary of Pollution	3
2	Population of Cities	7
3	Air and Water Temperatures	8
4	Surface Water Supplies	14
5	Location and Magnitude of Pollution	15
6	Pollution to Missouri River	16
7	Pollution to Tributaries, near Missouri River.	17
8	Dissolved Oxygen. Fish and Wildlife Service	21
9	Coliform Results - Water Works	22
10	Laboratory Results. Public Health Service	23
11	Low Winter Flows - 1940	26
12	Low Winter Flows - Low-Flow Years	27
13	Low Summer Flows - Low-Flow Years	28
14	Low Winter Discharge Frequency	29
15	Frequency of Flow Increases	34
16	Monthly Air and Water Temperatures	48

List of Figures

		Page
1	Sources of Pollution - Selected Laboratory Results	18
2	Main Stem Time of Travel Curves	25

Appendices

"A"	Laboratory Results - Public Health Service . . .	37
"B"	Oxygen Results - Fish and Wildlife Service . . .	42
"C"	Monthly Water and Air Temperatures	48

Introduction

The Office of the Chief of Engineers, U. S. Army, in a communication dated September 19, 1942, made inquiry as to the possibility of the U. S. Public Health Service conducting a survey to determine as nearly as practicable the minimum discharge required during the winter months to provide adequate flow for sanitary and water supply purposes from a proposed dam at Fort Randall, South Dakota, to the mouth. Accordingly, a memorandum was prepared under date of September 25, 1942, outlining a suggested brief survey for the purpose stated. The Office of the Chief of Engineers, in a communication dated October 31, 1942, expressed a desire that the Service undertake the proposed survey and suggested that the proposed plan of procedure be submitted to the District Engineer at Omaha, through the Division Engineer in the same city, for approval prior to actual initiation of the investigation. This was done under date of November 7, 1942, and the proposed plan of procedure was approved November 12, 1942.

A visit was made to the Missouri Valley from November 18 to December 6, 1942, to collect necessary information and outline assistance needed from the U. S. Engineer Office.

The Omaha District U. S. Engineer Office requested that a tentative summary of conclusions be submitted early in January, and this was done. The present report presents final conclusions which are little changed in essentials since the preliminary memorandum.

Summary

The Missouri is 2,475 miles long, drains 529,350 square miles, including 9,715 square miles in Canada, and has an average flow of 57,300 c.f.s. at Hermann, Missouri, 99 miles above the confluence with the Mississippi River above St.Louis. The lower 931 miles below the proposed dam at Ft. Randall, South Dakota, traverses or bounds the states of South Dakota, Nebraska, Iowa, Kansas and Missouri. Most of the major sources of pollution are on the lower Missouri River, and the Kansas City area creates the most serious pollution situation. The lower river is used as a source of water by purification plants supplying a population of 1,350,000 and receives sewage and industrial wastes having a sewered population equivalent of

3,000,000. Pollution of tributaries is relatively minor and has little effect on the main river. Ice cover affects the winter pollution problem in the upper reaches but becomes less important toward the mouth, until below Kansas City a frozen river is seldom experienced. A predominating characteristic of the Missouri River is its silt load, which detracts from the appearance. Apparently the silt load also is partially responsible for depressing dissolved oxygen levels and limits the amount of pollution that can be assimilated without damage. Since late in 1939, the flow of the river has been affected by the operation of Fort Peck Reservoir. Operation of the reservoir is planned to maintain a flow of 20,000 c.f.s. at Yankton, South Dakota, during the navigation season, March 15 to November 15, and a less definitely settled flow, possibly 7,000 c.f.s., during the winter months.

Conclusions

(1) Most of the cities along the lower Missouri River draw their public water supply from the river, Sioux City, Iowa, with a ground water supply, being the only notable exception. Because of excessive turbidities and number of coliform organisms present, a high degree of treatment is required.

(2) Sewage from a population of 1,205,000 and industrial wastes with a sewered population equivalent of 2,375,000, making a total of 3,580,000, are produced on the Missouri River and the lower reaches of tributaries. Treatment in municipal sewage treatment plants reduces the total pollution load by 370,000, to 3,210,000, prior to discharge. Practically all of the treatment is on tributaries. A summary of pollution loads is shown on Table 1.

(3) Water works laboratory data indicate high coliform results over the entire length of the lower river, and U. S. Fish and Wildlife Service oxygen results indicate increasing dissolved oxygen deficits from below Sioux City to below Kansas City as pollution loads become greater.

(4) The effect of flow regulation by Fort Peck reservoir and the proposed Fort Randall reservoir will be beneficial to the pollution problem if winter flows are not too greatly depressed, as flows during critical low-flow summer months will be increased.

Table 1 Missouri River Investigation - Summary of Sources of Sewage and Industrial Waste Pollution and Reduction by Present Treatment in Municipal Sewage Treatment Plants.

Description	Pollution Load		
	Missouri River (1)	Tributaries Near (2) Missouri R.	Total
	Sewered Population or Equivalent (B.O.D.) Rounded to Nearest 10,000		
Sewered Population	930,000	275,000	1,205,000
Industrial Wastes	2,200,000	175,000	2,375,000
Total Before Treatment (3)	3,130,000	450,000	3,580,000
Reduction by Treatment (3)	50,000	320,000	370,000
Residual After Treatment (3)	3,080,000	130,000	3,210,000

(1) Below Fort Randall, Mile 931.
(2) Small communities within 50 miles. Larger cities within 100 miles.
(3) In municipal sewage treatment plants.

(5) The question of ice cover below Fort Randall is important in the pollution problem below Sioux City and Omaha but is of lesser importance as the stream flows south. Ice cover below Kansas City is of minor importance, as the river has frozen over only twice in 40 years of record. These two instances were of only a few days' duration, and indications are that ice cover was not "complete."

(6) The estimate of winter low-flow requirements for pollution control in order to prevent creation of additional pollution damage during normal winters is 5,500 c.f.s. at Yankton, South Dakota, or 8,000 c.f.s. below Kansas City.

(7) It cannot be said definitely that such flow will maintain any specific oxygen levels. However, the percentages of ice cover which will permit winter dissolved oxygen to be maintained at various average monthly levels are estimated as follows:

Monthly Average Dissolved Oxygen Parts per Million	3.0	5.0	6.5
	Per Cent of Ice Cover		
Sioux City to Omaha	100	100	100
Omaha to St. Joseph	95	91	86
St. Joseph to Kansas City	93	90	86
Below Kansas City	90	88	84

Daily dissolved oxygen results 1.5 to 2.0 p.p.m. lower may be expected.

(8) During severe winters, slow, relatively minor winter fluctuations of flow may be necessary to induce cracking and drawing ice away from the shore, should "complete" ice cover create critical conditions. Additional flow required to create necessary fluctuations may increase the average winter flow requirement at Yankton by 1,000 c.f.s., to 6,500 c.f.s. The possibility of creating ice gorges or other dangerous complications should be investigated.

(9) From a study of past records, it is estimated that maintaining 5,500 winter flow at Yankton will increase the minimum monthly winter flow 18 per cent of the years and will decrease it 82 per cent of the years. Maintaining summer flows

of 20,000 c.f.s. at Yankton will increase the minimum monthly summer flows 77 per cent of the years and decrease it 23 per cent of the years.

(10) While bacterial pollution of the Missouri River is heavy and public water supplies drawn from the river require a high degree of treatment, proposed flow regulation will have little if any effect on the expected concentration of coliform bacteria, an intestinal organism.

(11) While proposed regulation of the Missouri River will improve the situation, pollution conditions will remain generally unsatisfactory, and treatment of sewage and correction of industrial waste pollution are ultimate probabilities.

(12) New war industries and temporary war expansions of existing industries have not been considered in this report. Such industries will undoubtedly further depress oxygen levels in the Missouri River. Under the circumstances, additional flow would be desirable. However, the ratio of summer to winter flows of 20,000 c.f.s. to 5,500 c.f.s. would probably still be most advantageous and neither should be increased at the expense of the other.

Description

The Missouri River is 2,473 miles long, and drains 529,350 square miles, including 9,715 square miles in Canada. The main Missouri River forms at Three Forks, Montana, and discharges into the Mississippi River at St. Louis.

The present report deals with the lower Missouri River from Fort Randall, South Dakota, 931 miles above the mouth and 82 miles above Yankton, S. D., to the mouth. From Fort Randall the river flows southeasterly to Kansas City, forming the state boundaries of South Dakota, Nebraska, Iowa, Missouri and Kansas. From Kansas City the river flows easterly across the State of Missouri to St. Louis. The larger tributaries below Fort Randall are as follows:

Tributaries	Distance Above Mouth of Missouri R.	Drainage Area, Square Miles
Gasconade River	105.4	3,600
Osage River	131.6	15,300
Grand River	254.8	7,900
Kansas River	381.9	61,440
Nishnabotna River	564.6	2,942
Platte River(Nebr.)	613.0	90,200
Little Sioux River	702.3	4,260
Big Sioux River	771.2	9,415
James River	843.5	22,100
Niobrara River	894.2	13,000

The largest concentrations of population in the Missouri River basin are along the lower Missouri River. Populations of the larger cities during the past 20 years are shown on Table 2.

U. S. Weather Bureau normal air temperature records and municipal water works water temperature records are summarized on Table 3. Table 16, Appendix "C," presents detailed water and air temperature records.

Navigation in the lower Missouri River from March 15 to November 15 is dependent upon the maintenance of a sustained flow in the river, and operation of Fort Peck Dam and the proposed Fort Randall Dam will be governed to a considerable degree by navigation requirements.

Table 2 Missouri River Investigation - U.S.Census Populations of Larger Cities On or Near the Missouri River Below Fort Randall,S.D.

City	Population		
	1920	1930	1940
Cities on Main Missouri River			
Yankton, S. Dak.	5,024	6,072	6,798
Sioux City, Iowa	71,227	79,183	82,364
South Sioux City,Nebr.	2,402	3,927	4,556
Omaha, Nebr.	191,601	214,006	223,844
Council Bluffs, Iowa	36,162	42,048	41,439
St.Joseph, Mo.	77,939	80,935	75,711
Atchison, Kans.	12,630	13,024	12,648
Leavenworth, Kans.	16,912	17,466	19,220
Kansas City, Kans.	101,177	121,857	121,458
Kansas City, Mo.	324,410	399,746	399,178
Independence, Mo.	11,686	15,296	16,066
Jefferson City, Mo.	14,490	21,596	24,268
St.Charles, Mo.	8,503	10,491	10,803
Cities on Tributaries, Near Missouri River			
Sioux Falls, S. Dak.	25,202	33,362	40,832
Lincoln, Nebr.	54,948	75,933	81,984
Topeka, Kans.	50,022	64,120	67,833
Lawrence, Kans.	12,456	13,726	14,390

Table 3 Missouri River Investigation - Monthly Mean Normal Air Temperatures as Reported by U. S. Weather Bureau, and Monthly Mean Water Temperatures as Reported by Municipal Water Works Officials.

Month	Yankton S. D.	Sioux City	Omaha Nebr.		Kansas City (Airport)		St. Louis (City Office)	
	Degrees Fahrenheit. (A)-Air (W)-Water							
	(Air)	(Air)	(A)	(W)	(A)	(W)	(A)	(W)
January	14	18	21	35	28	35	31	37
February	17	21	26	35	31	36	37	37
March	31	33	37	40	43	42	44	45
April	46	48	51	51	55	52	56	55
May	58	60	62	63	65	65	67	67
June	67	70	72	73	74	74	75	75
July	73	74	77	80	78	80	79	81
August	71	72	74	79	77	79	78	79
September	62	63	67	71	69	71	71	73
October	49	51	54	59	58	60	59	61
November	33	35	39	43	44	44	45	48
December	20	23	26	36	33	36	35	39
Annual	45	47	51	55	54	56	56	58

Previous Investigations

Previous investigations include a bacterial study made by the U. S. Public Health Service in 1912 and periodic sampling by the Fish and Wildlife Service during the past ten years.

The results of the previous investigation of the pollution of the Missouri River conducted by the U. S. Public Health Service in 1912 were published as Hygienic Laboratory Bulletin No. 89, May, 1913. This investigation covered "The Missouri River from Sioux City to Its Mouth," and was Number VI of a series on "Sewage Pollution of Interstate and International Waters with Special Reference to the Spread of Typhoid Fever." As its title indicates, the investigation was chiefly concerned with the bacterial pollution problem, which is of secondary importance in the present investigation. However, certain observations of interest in the report are as true today as in 1913. Excerpts of interest are as follows:

> (Page 13) "In a study of pollution of the lower Missouri River certain facts are prominent as having an important bearing on the subject. First, the character of the rural districts is such that considerable animal pollution is certain to reach the streams; second, the population per square mile is not excessive, and in many of the rural districts is decreasing; third, very significant pollution comes from the large cities, and the population of these cities is increasing.
>
> "The rural population in Iowa and Missouri has reached beyond 27 (1910 - 27.8 Ia., 27.6 Mo.; 1940 - 26.0 Ia., 26.3 Mo.) persons to the square mile and is now decreasing. The rural population in Kansas and Nebraska is only 14.6 (1940 - 12.8) and 11.5 (1940 - 10.5) respectively; hence, the slight increase in rural population is to be expected. It may be accepted, judging by the experience of older states, that the rural population per square mile will not exceed 30, certainly not for many years.
>
> "The large rural population with the great number of domestic animals is sufficient to contribute to the streams draining this area a considerable degree of pollution, especially when heavy rains and thaws wash the surface pollution into the streams.
>
> "This rural pollution may be accepted as inevitable. On the other hand, the pollution of the streams from urban sources is very great, is constantly

increasing, is susceptible of control, and should be very carefully controlled.

"In addition to the pollution of the Missouri River by rural communities, there is a certain amount of pollution from tributary streams receiving sewage from cities or towns of less than 5,000 population. If these towns are situated at considerable distances from the main river, they may be considered in the same category as rural pollution, because of the effect of stream flow on the small amount of sewage contributed. Besides the rural pollution and distant pollution from these small cities, there remains to be considered the most important class of contributors to the pollution of the Missouri, viz, the large cities. Some of these cities are growing rapidly, and in addition to the sewage, have packing plants which discharge large quantities of wastes into the Kansas and Missouri Rivers."

(Page 23) "In view of these circumstances (high flows and silt) the sewage of small urban communities of less than 5,000 people can not have a marked effect upon the character of the Missouri River water for more than a few miles beyond the sewer outlets. Yet at Jefferson City, 240 miles below Kansas City and 54 miles below Boonville (which has less than 3,000 people tributary to sewers) a B.coli content of from 150 to 300 per cubic centimeter was found. The most logical explanation, and an inference which is unavoidable, is that the high B.coli count in Missouri River water is due largely to the washings from the rather populous watershed. "Populous" is used here to indicate not only human beings per square mile but also cattle and hogs. Independent of city sewage, the tributary streams and the Missouri itself receive in flood times the washings of manured fields, grazing land, and hog farms, as well as the washed-out contents of privy vaults, cesspools, and small sewerage systems."

(Page 43) "Sewage pollution of the lower Missouri River is general from Sioux City to its mouth, while it is greater in the vicinity of cities and packing plants. It is also marked at points on the river far removed from cities. At such points, after many miles of stream flow from the nearest urban source (54 miles at Jefferson City or 23 miles at Quindaro) the B.coli content is still as high as 150 to 300 per cubic cen-

timeter during certain months. This necessitates a high degree of purification in order to make Missouri River water safe."

(Page 45) "The Missouri River at points farthest removed from the greatest sources of sewage pollution furnishes a raw water for drinking purposes which not only is unfit for drinking without treatment, but which requires very thorough treatment to render it safe."

As mentioned later, the U. S. Fish and Wildlife Service of the Department of the Interior has sampled the Missouri River from time to time and has made various determinations, of which the dissolved oxygen results are of interest at the present time. The results have not been published but have been made available in connection with the present investigation.

Survey Methods

In view of the present war situation, a comprehensive investigation of the pollution problem on the Missouri River was considered neither possible, justified nor necessary for present purposes. The investigation has therefore consisted primarily of the assembly, tabulation, presentation and study of existing information. A large fund of information from various sources has been found to exist, with the result that conclusions have been drawn with a reasonable degree of assurance. The principal lack that has been felt has been due to the paucity of data on oxygen conditions under ice in the Missouri River. Even here, limited information is available on oxygen conditions under ice at Bismarck, N. D. Information is also available on reaeration at open water near dams on ice-covered streams.

Four different types of information have been collected, tabulated and analyzed, as follows:

(1) Air temperature and river ice records.
(2) Data on sources of pollution.
(3) Laboratory data.
(4) Hydrometric data.

Air temperature records are important, due to their close relationship to river water temperatures, which are determin-

ing factors governing dilution requirements for pollution control. Long-time records of air temperatures are available in publications of the U. S. Weather Bureau.

Ice records, also of the U. S. Weather Bureau, were studied in connection with a determination of the importance of ice cover in creating critical winter pollution conditions. These records are not published in comprehensive form, so they were examined at local Weather Bureau offices in Sioux City, Omaha and Kansas City. Day-to-day comments of the observer were of particular interest in studying the completeness of the ice cover.

Data on public surface water supplies and sewage pollution were obtained from a "Census of Water Treatment Plants" and a "Census of Sewer Systems and Sewage Treatment Plants," presenting information collected by the various State health departments and tabulated by the Stream Pollution Investigations Station of the U. S. Public Health Service. Estimates of industrial waste pollution loads have been based on the magnitude of the meat packing industry indicated in publications of the U. S. Bureau of Animal Industry and indications made of the magnitude of other industries by local Chambers of Commerce.

Dissolved oxygen data have been furnished by the U. S. Fish and Wildlife Service, through the helpful co-operation of Dr. M. M. Ellis, Senior Aquatic Physiologist. This information includes the only long-time available record of oxygen conditions in the Missouri River.

In connection with other activities, the U. S. Public Health Service Trailer Laboratory No. 4, with its staff under the direction of Assistant Sanitary Chemist Morris B. Ettinger, was assigned during December, 1942, to conduct a brief laboratory study of the Missouri River above and below Kansas City in connection with a wartime pollution problem. The work was done at the request of the Missouri State Board of Health. Assistance during the work was furnished by the Division of Engineering of the State Board of Health, under the direction of W. Scott Johnson, Chief Public Health Engineer. Results have been made available through the co-operation of the State of Missouri and of the District Director, District No. 7, and the Stream Pollution Investigations Station, both of the U. S. Public Health Service.

Hydrometric data have been compiled by the Omaha District, U. S. Engineer Office, from their own and U. S. Geolog-

ical Survey records. These data include tabulations of the monthly average flows of record, curves indicating flow velocities at various points, and a tabulation of the sources of water during a typical winter low-flow period.

Presentation of Field Data

Figure 1 shows the location and magnitude of each source of pollution on the lower Missouri River and on the portion of tributaries near the Missouri River. Other items shown are water supply intakes, state lines and the location of the proposed Fort Randall Dam.

Public Water Supplies. There are 15 public water supplies taken from the Missouri River to supply a population of about 1,350,000 and pumping 174 million gallons per day. The individual supplies are listed on Table 4.

Sources of Pollution. Table 5 summarizes the location and magnitude of sources of residual pollution, and Tables 6 and 7 show, for cities on and near the Missouri respectively, the sewered population, sewered population equivalent including industrial wastes and residual pollution discharged following treatment in municipal sewage treatment plants. There is very little treatment of sewage of main Missouri River cities, and where sewage treatment is practiced it is usually where discharge is to a small stream rather than direct to the Missouri River. Treatment of sewage on tributaries is quite extensively practiced and reduction of pollution of 71 per cent is being accomplished. Treatment plants at Sioux Falls, South Dakota, Lincoln, Nebraska, and Topeka, Kansas, accomplish notable reductions in pollution.

By far the largest source of industrial wastes on the lower main Missouri River is the meat packing industry, which contributes over 90 per cent of the industrial pollution load.

Table 4 Missouri River Investigation - Surface Water Supplies Taken from Missouri River Below Fort Randall.

(Data from U.S.P.H.S. Census of Water Treatment Plants)

Supply	State	Mile (1)	Treatment (2)	Population Served	Consumption M.G.D.
Yankton	S.Dak.	849.3	FD	6,600	0.45
Omaha	Nebr.	637.2	FD	225,000	28.0
Council Bluffs	Iowa	637.2	SD	43,500	4.0
Nebraska City	Nebr.	581.5	SD	(3) 7,000	(3) .7
St.Joseph	Mo.	461.4	FD	56,000	8.0
Atchison	Kans.	436.6	SD	12,500	1.82
Leavenworth	Kans.	413.4	FD	18,000	1.5
Kansas City	Kans.	380.5	FD	160,000	18.3
Kansas City	Mo.	380.5	FD	475,000	62.0
Lexington	Mo.	323.7	FD	4,200	.2
Glasgow	Mo.	230.2	FD	1,000	.05
Boonville	Mo.	198.9	FD	5,800	.50
Jefferson City	Mo.	145.6	FD	17,300	1.75
St.Charles	Mo.	27.8	FD	9,900	.55
St.Louis (4)	Mo.	0.0	FD	(3)310,000	46.1
Total				1,391,800	173.92

(1) Location in miles above mouth of Missouri River.
(2) F-coagulated, settled, filtered. S-coagulated, settled. D-chlorinated.
(3) Estimated.
(4) Howard B end plant only.

Table 5 Missouri River Investigation - Summary of Location and Magnitude of Sources of Residual Pollution Below Fort Randall in Terms of Sewered Population Equivalent (B.O.D.)

District	Sewered Population or Equivalent
Sioux City	345,000
Omaha	915,000
St.Joseph	375,000
Leavenworth	215,000
Kansas City	1,200,000
B elow Kansas City	30,000
Tributaries, Near Missouri River	130,000
Total	3,210,000

Table 6 Missouri River Investigation - Sources of Pollution Including Industrial Wastes Expressed as Sewered Population Equivalent (B.O.D.) Discharging to Missouri River.

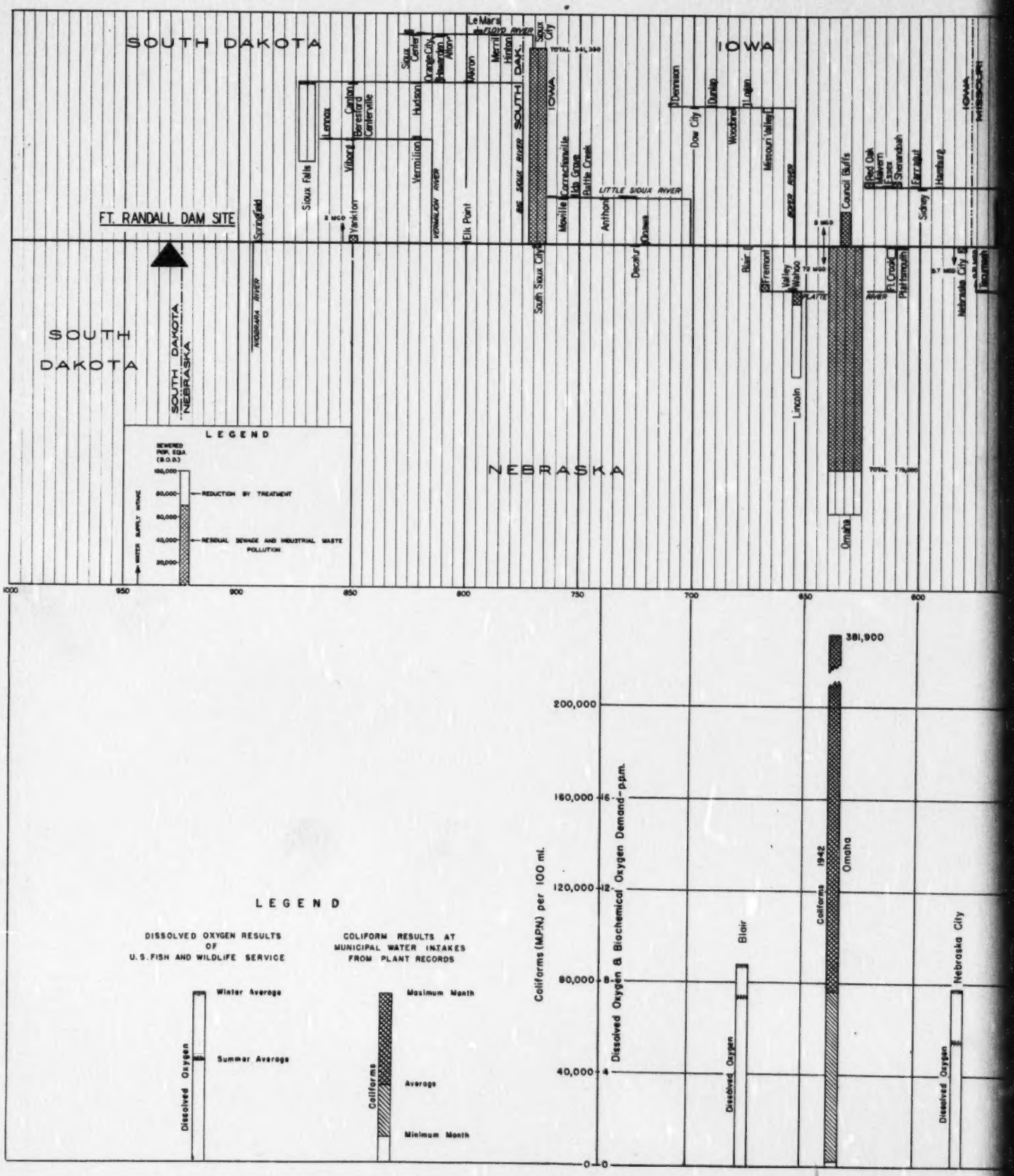
Municipality	State	Mile (1)	Population Connected to Sewers	Treatment	Sewered Population Equivalent (B.O.D.)	
					Untreated(3)	Discharged
Fort Randall	S.Dak.	931				
Springfield	"	882	600	None	600	600
Yankton	"	849	6,000	"	6,000	6,000
Elk Point	"	799	1,000	"	1,000	1,000
Sioux City	Iowa	769	71,300	"	341,300	341,300
South Sioux City	Nebr.	769	3,500	"	3,500	3,500
Onowa	Iowa		2,300	Primary	2,300	1,500
Decatur	Nebr.	726	700	Secondary	700	100
Blair	"	676	2,800	None	2,800	2,800
Omaha	"	637	214,000	Secondary (2)	934,000	883,000
Council Bluffs	Iowa	637	29,000	None	29,000	29,000
B ellevue	Nebr.	613	1,000	"	1,000	1,000
Plattsmouth	"	609	3,000	"	3,000	3,000
Nebraska City	"	582	5,000	"	5,000	5,000
St.Joseph	Mo.	461	73,000	"	373,000	373,000
Atchison	Kans.	437	12,000	"	22,000	22,000
Leavenworth	"	413	14,000	"	214,000	214,000
Kansas City	"	381	90,000	"	790,000	790,000
Kansas City	Mo.	381	360,000	"	360,000	360,000
Independence	"	364	7,200	"	7,200	7,200
Lexington	"	324	2,300	"	2,300	2,300
Glasgow	"	230	700	"	700	700
Jefferson City	"	146	18,300	"	18,300	18,300
Hermann	"	99	1,500	"	1,500	1,500
Washington	"	69	5,300	"	5,300	5,300
St.Charles	"	28	7,900	"	7,900	7,900
Total			932,400		3,132,400	3,080,000

(1) Location in miles above mouth of Missouri River.
(2) Portion of sewage treated.
(3) Includes industrial wastes from incomplete survey.

Table 7 Missouri River Investigation - Sources of Pollution Including Industrial Wastes Expressed as Sewered Population Equivalent (B.O.D.) Discharging to Tributaries, Near Missouri River.

Municipality	State	Mile (1)	Population Connected to Sewers	Treatment	Sewered Population Equivalent (B.O.D.)	
					Untreated	Treated
Vermillion R.Mouth		815				
Vermillion	S.Dak.	7	2,700	None	2,700	2,700
7 Small Sources	"		7,200	Various	7,200	2,600
Big Sioux R.Mouth		771				
Sioux Falls	"	98	33,600	Second'y	140,000	2,600
Howarden	Iowa	40	2,100	None	2,100	2,100
3 Small Sources			3,400	"	3,400	3,400
Floyd River Mouth		767				
Sheldon	Iowa	56	3,100	Primary	3,100	2,000
Le Mars	"	25	3,600	None	3,600	3,600
8 Small Sources	"		5,900	Various	5,900	2,200
Boyer R. Mouth		656				
Dennison	"	54	3,500	None	3,500	3,500
Missouri Valley	"	12	4,000	"	4,000	4,000
4 Small Sources	"		3,800	"	3,800	3,800
Platte R. Mouth		613				
Fremont	Nebr.	58	12,000	"	12,000	12,000
Wahoo	"	46	2,500	"	2,500	2,500
Lincoln	"	44	75,000	Second'y	75,000	11,000
3 Small Sources	"		2,300	Various	2,300	1,500
Nishnabotna, Mouth		565				
Red Oak	Iowa	58	4,600	None	4,600	4,600
Shenandoah	"	46	5,500	"	5,500	5,500
6 Small Sources	"		4,600	Various	4,600	3,400
Big Nemaha R.Mouth		514				
Falls City	Nebr.	16	5,000	None	5,000	5,000
3 Small Sources	"		4,500	Various	4,500	3,900
Kansas River		382				
Topeka	Kans.	78	40,000	Second'y	110,000	16,000
Lawrence	"	49	13.000	None	13,000	13,000
3 Small Sources	"		2,400	"	2,400	2,400
Grand R. Mouth		255				
Brookfield	Mo.	50	4,200	Second'y	4,200	600
Chillicothe	"	50	6,100	None	6,100	6,100
Brunswick	"	3	900	"	900	900
Lamine R. Mouth		205				
Slater	"	40	2,000	Primary	2,000	1,300
Marshall	"	33	5,700	Second'y	5,700	900
Other Tributaries						
21 Small Sources			14,200	Various	14,200	6,900
Total			277,400		453,800	130,000

(1) River mouth mileages to mouth of Missouri River.
Others to mouth of tributary.


SOUTH DAKOTA
IOWA
NEBRASKA
FT. RANDALL DAM SITE
SOUTH DAKOTA
NEBRASKA
SOUTH DAKOTA
LEGEND
SEWERED POP. EQA. (B.O.D.)
REDUCTION BY TREATMENT
RESIDUAL SEWAGE AND INDUSTRIAL WASTE POLLUTION
WATER SUPPLY INTAKE
Sioux Falls
Lennox
Canton
Beresford
Centerville
Vermillion
Hudson
Sioux Center
Orange City
Hawarden
Alton
Le Mars
Akron
Merrill
Hinton
Sioux City
TOTAL 340,300
Denison
Dow City
Dunlap
Woodbine
Logan
Missouri Valley
Council Bluffs
Red Oak
Essex
Shenandoah
Farragut
Hamburg
Sidney
Springfield
Yankton
Elk Point
Moville
Correctionville
Ida Grove
Battle Creek
Anthon
Odebolt
Decatur
South Sioux City
Blair
Fremont
Valley
Walhoo
Lincoln
Omaha
Ft. Crook
Plattsmouth
Nebraska City
Tarkio
TOTAL 778,000
1000
950
900
850
800
750
700
650
600
LEGEND
DISSOLVED OXYGEN RESULTS OF U.S. FISH AND WILDLIFE SERVICE
Winter Average
Summer Average
Dissolved Oxygen
COLIFORM RESULTS AT MUNICIPAL WATER INTAKES FROM PLANT RECORDS
Maximum Month
Average
Minimum Month
Coliforms
Coliforms (M.P.N.) per 100 ml.
Dissolved Oxygen & Biochemical Oxygen Demand - p.p.m.
381,900
200,000
160,000
120,000
80,000
40,000
0
16
12
8
4
0
Blair
Coliforms 1942
Omaha
Nebraska City
Dissolved Oxygen

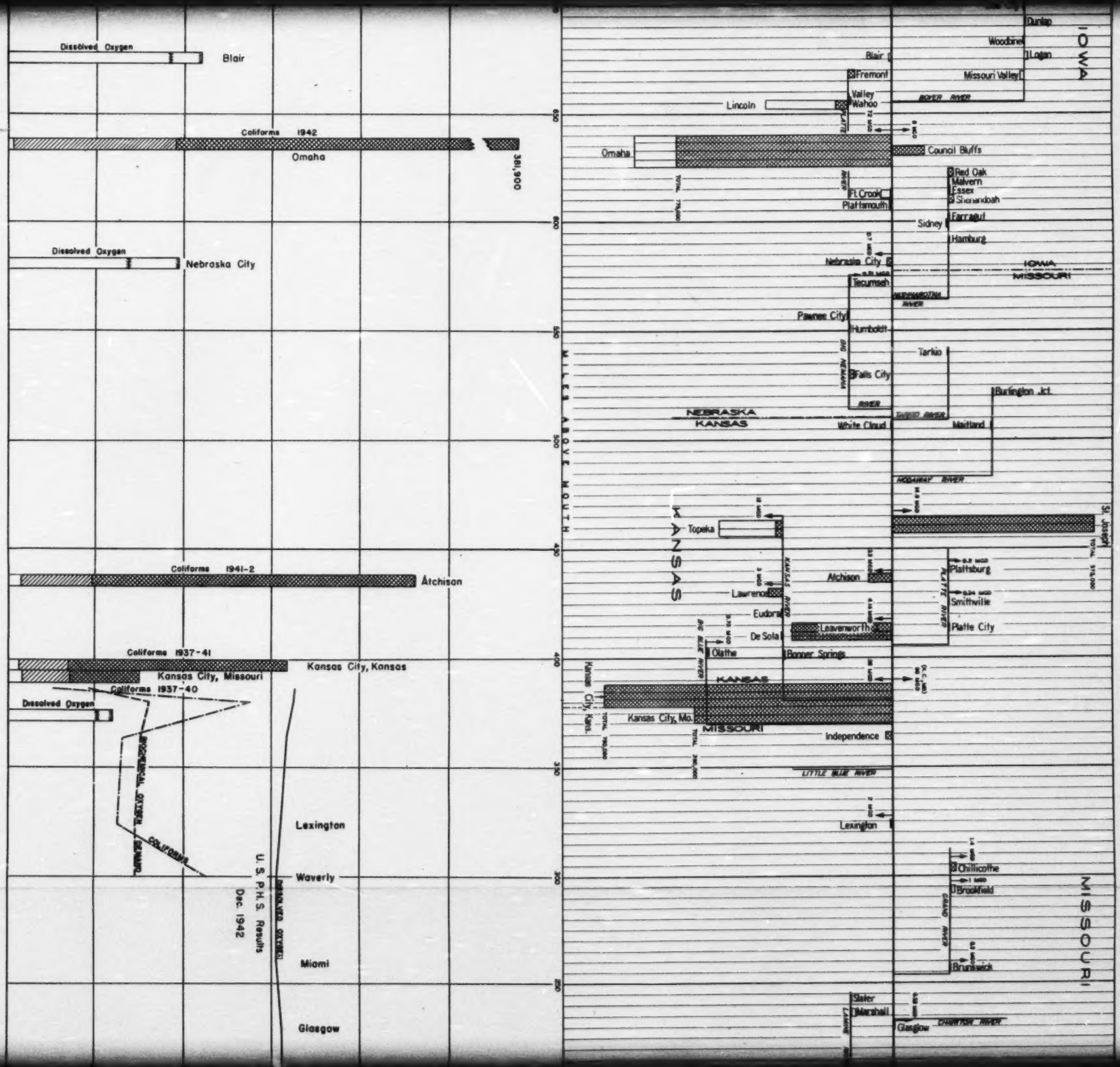

Dissolved Oxygen
Blair
Coliforms 1942
Omaha
381,900
Dissolved Oxygen
Nebraska City
Coliforms 1941-2
Atchison
Coliforms 1937-41
Kansas City, Missouri
Kansas City, Kansas
Coliforms 1937-40
Dissolved Oxygen
BIOCHEMICAL OXYGEN DEMAND
COLIFORMS
U. S. P. H. S. Results
Dec. 1942
DISSOLVED OXYGEN
Lexington
Waverly
Miami
Glasgow
600
550
500
450
400
350
300
250
MILES ABOVE MOUTH
Blair
Fremont
Valley
Wahoo
Lincoln
Omaha
Council Bluffs
Ft. Crook
Plattsmouth
Nebraska City
Tecumseh
Pawnee City
Humboldt
Falls City
White Cloud
Topeka
Atchison
Lawrence
Eudora
De Soto
Leavenworth
Olathe
Bonner Springs
Kansas City, Mo.
Independence
Lexington
Dunlap
Woodbine
Logan
Missouri Valley
Red Oak
Malvern
Essex
Shenandoah
Farragut
Sidney
Hamburg
Tarkio
Burlington Jct.
Maitland
St. Joseph
Plattsburg
Smithville
Platte City
Chillicothe
Brookfield
Brunswick
Slater
Marshall
Glasgow
IOWA
MISSOURI
NEBRASKA
KANSAS
KANSAS
MISSOURI
MISSOURI
BOYER RIVER
PLATTE RIVER
NISHNABOTNA RIVER
NODAWAY RIVER
KANSAS RIVER
BIG BLUE RIVER
LITTLE BLUE RIVER
GRAND RIVER
CHARITON RIVER
LAMINE RIVER

FIGURE 1.

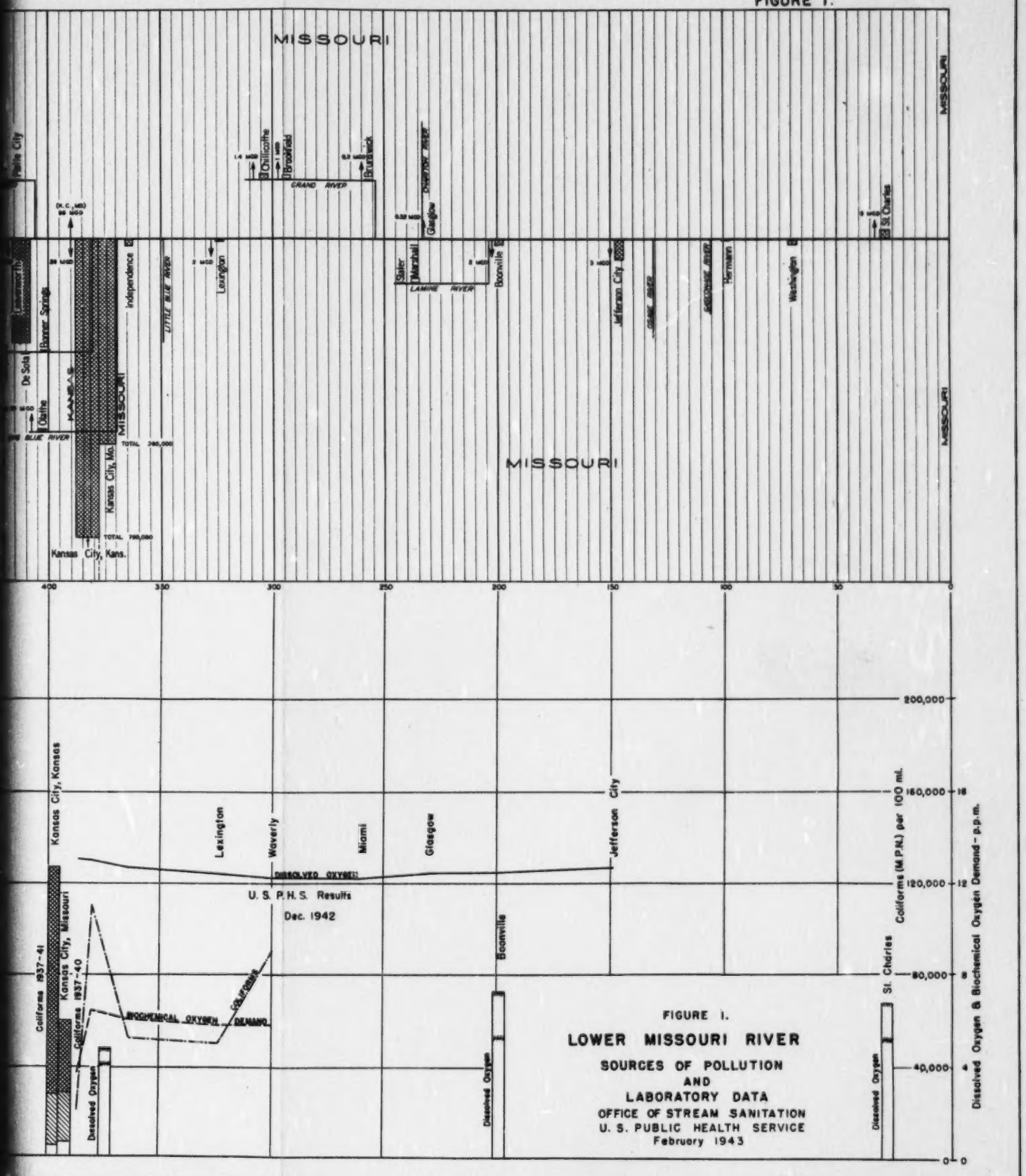


FIGURE 1.

LOWER MISSOURI RIVER

SOURCES OF POLLUTION
AND
LABORATORY DATA

OFFICE OF STREAM SANITATION
U. S. PUBLIC HEALTH SERVICE
February 1943

Presentation of Laboratory Data

Three sources of laboratory data have been considered during the present investigation, namely: (1) dissolved oxygen results over a period of years, made available through co-operation of the Fish and Wildlife Service of the U. S. Department of the Interior, (2) coliform results at public water supply intakes, made available through the co-operation of water works officials, and (3) the results of stream sampling during December, 1942, by a U. S. Public Health Service trailer laboratory.

The dissolved oxygen results of the U. S. Fish and Wildlife Service are shown in Appendix "B" of this report, and averages are summarized in Table 8. These results show the progressive reduction in dissolved oxygen below Sioux City at Blair, below Omaha at Nebraska City, and below Kansas City, followed by partial recovery at Boonville and St. Charles.

The individual results fluctuate quite widely and show only slight relationship between stream flow and dissolved oxygen until Boonville is reached. Here a fairly definite trend is apparent, the low oxygen results being obtained during low-flow periods. A probable explanation of the fluctuating results is that oxygen is depressed not only by sewage and industrial waste pollution but also by surface wash. This might be expected in view of the tremendous silt load carried by the river. Abnormally high coliform results also indicate the effect of surface wash and rural pollution. While sewage and industrial waste affect oxygen levels throughout the lower Missouri River, it is apparent that, as a consequence of the importance of surface wash, a large source of sewage and industrial waste pollution is required before the effects greatly predominate the situation. On a clear stream, relatively small sources of pollution may predominate and there is a quite definite relationship between flows and dissolved oxygen levels.

The Fish and Wildlife Service results show a definite and expected relationship between temperature and dissolved oxygen.

Laboratory results of numbers of coliforms, an intestinal organism, covering various periods, were secured from municipal water works officials at Omaha, Nebraska, Atchison and Kansas City, Kansas, and Kansas City, Missouri. Maximum, minimum and average laboratory results are summarized on Table 9. Normally,

no great refinements are taken in the coliform determination on raw water, as the quality of finished water is more important. While a detailed review of analytical methods has not been made, brief inquiry indicates that laboratory techniques are not uniform in the various laboratories. The results at Kansas City, Kansas, are generally agreed to be the most reliable. The results at Atchison, Kansas, were made by the Kansas State Board of Health and are reliable for the samples examined, although the determinations were, of necessity, made on transported samples.

A brief investigation has been made of possible correlation between coliform results and stream flows. The relationship is not marked but, in general, the lowest coliform concentrations were found at times of lowest flow. As flows increase, the coliform concentration also increases. This is attributed, first, to the importance of surface wash and, second, to a decreased time of flow from points of pollution with increased velocity of flow. Coliform death rates are rapid, so that reduction in time of flow more than offsets increased dilution. However, as flows increase further, approaching flood flows in magnitude, dilution becomes a dominating factor and coliform counts decrease.

From the standpoint of a consideration of winter oxygen conditions, the present investigation has been fortunate in having the results of a sampling and laboratory study of a U. S. Public Health Service trailer laboratory conducted for the State of Missouri during December, 1942, in connection with a war activity pollution problem. Determinations included alkalinity, pH, dissolved oxygen, biochemical oxygen demand, and coliforms. Over 100 samples were collected and nearly 400 individual determinations made. The individual results are shown in Appendix "A" and averages are summarized on Table 10.

The biochemical oxygen demand determinations show an increase in passing Kansas City, followed by a reasonable rate of reduction after the increase. The dissolved oxygen results show a shallow but regular oxygen sag below Kansas City.

Table 8 Missouri River Investigation - Average Dissolved Oxygen in Missouri River, 1933-1942, from Results of Water Quality Laboratories, U.S. Fish and Wildlife Service, Columbia, Missouri.

Location	Blair Nebraska	Nebraska City Nebraska	Below Kansas City Missouri	Boonville Missouri	St.Charles Missouri
Mile	676	582	380-368	199	28
Average Dissolved Oxygen Results in Parts Per Million					
January	8.8	7.8	4.4	7.3	6.9
February	8.2	7.3	4.9	6.8	6.5
March	8.4	7.5	4.7	6.9	6.9
April	8.3	7.4	3.7	6.7	6.9
May	7.7	6.1	4.1	6.3	6.1
June	7.9	5.9	4.0	5.5	5.7
July	7.5	5.0	3.7	5.0	5.5
August	6.9	4.9	3.7	5.1	4.6
September	6.9	5.6	4.5	5.2	5.1
October	7.2	5.7	3.8	6.2	5.9
November	9.0	9.0	4.2	6.9	7.4
December	9.1	8.1	4.7	7.4	7.1
Average	8.0	6.7	4.2	6.3	6.2

Table 9 Missouri River Investigation - Coliform Results on Raw Missouri River Water, as Reported by Municipal Water Works Officials.

Place	Mile	Year	Monthly Average Coliforms Most Probable Number per 100 ml.		
			Maximum	Minimum	Average
Omaha, Nebr.	637	1942	381,900	316	75,800
Atchison, Kans.	437	1941	184,000	5,300	42,200
		1942	72,100	9,200	32,600
Kansas City, Kans.	382	1937	39,200	6,800	20,800
		1938	29,500	5,000	18,100
		1939	43,100	7,000	24,200
		1940	74,700	5,900	29,100
		1941	126,000	10,500	44,900
Kansas City, Mo.	382	1937	53,700	15,400	35,400
		1938	49,000	14,400	28,800
		1939	36,300	6,600	21,700
		1940	59,200	8,800	26,100

Table Missouri River Investigation - Average Laboratory Results from Missouri and Kansas Rivers from Above Kansas City, Kansas, to Jefferson City, Missouri, on Samples Collected During December, 1942.

Sampling Point	Mileage	Samples	Date Dec., 1942	Average Discharge c.f.s.	Temperature °C.	Dissolved Oxygen		B.O.D. 5-day 20°C.	Coliforms per Ml.	pH	Alkalinity p.p.m.
						D.O.	% Sat.				
Missouri R. above K.C.	387	5	14-23	9,310	2.6	12.94	94.3	3.62	205	7.9	261
Kansas R. above K.C.	387	5	14-23	3,160	2.8	13.50	99	3.53	69	8.2	304
" - Mouth	382	5	14-23	3,160	1.7	13.18	94.3	17.52		8.2	286
Missouri R. below Kansas R.	380	5	14-23	14,960	1.7	12.90	92.3	6.37	1,095	7.9	267
" below K.C.	364	5	14-20	15,020	1.7	12.58	90.0	5.93	514	7.9	280
" at Lexington	324	6	11-22	15,380	1.5	12.33	87.7	5.73	493	7.9	
" " Waverly	300	6	11-22	14,350	1.8	12.12	86.9	5.76	893	8.0	
" " Miami	262	2	11 & 26	15,500	3.2	12.16	90.8				
" " Glasgow	230	2	11 & 26		4.4	12.39	95.1				
" " Boonville	199	2	11 & 26		4.6	12.46	96.3				
" " Jeff.City	125	2	11 & 26		3.8	12.68	95.7				

Hydrometric Data

Hydrometric data collected and tabulated by the Omaha District, U. S. Engineer Office, included mean monthly discharges for all Missouri River gaging stations below Fort Randall and the lowest gaging stations on all major tributaries for the period of record. For correlating laboratory data, daily flows were taken from U. S. Geological Survey publications. Preliminary flow figures covering the December, 1942, sampling were also furnished by the U. S. Geological Survey.

Velocity-of-flow studies were conducted by the Omaha District, U. S. Engineer Office, both at gaging stations and at intermediate points. The conclusions of this s tudy are shown on Figure 2.

Table 11 shows flow conditions during the low winter flow period of January and February, 1940. In determining the relative flow at various points for the purpose of preparing estimates, this table and a similar table showing mean flows of record were used as guides.

Tables 12 and 13 show, for winter and summer respectively, the mean monthly flows in which the lowest seasonal flows have occurred. Years were selected when low flows occurred on the Missouri River, so that the lowest tributary flows are not necessarily indicated.

A brief study was made of the frequency of low monthly average winter flows during the period of record. Such a study, coupled with information on damaging pollution conditions in the past, is a valuable guide in estimating minimum winter flow requirements. A summary of the results of this study is presented in Table 14.

Figure 2

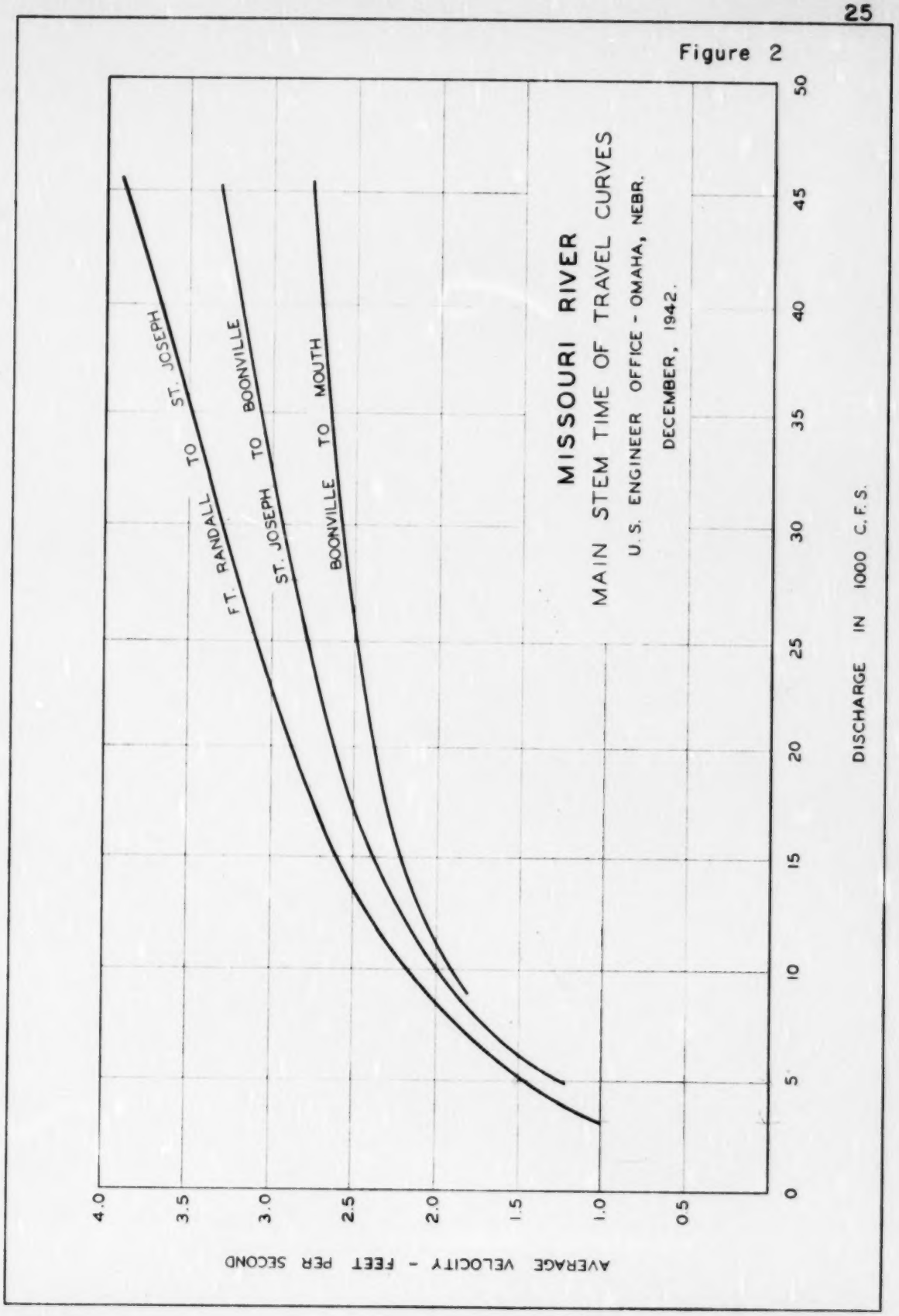

MISSOURI RIVER
MAIN STEM TIME OF TRAVEL CURVES
U.S. ENGINEER OFFICE - OMAHA, NEBR.
DECEMBER, 1942.
FT. RANDALL TO ST. JOSEPH
ST. JOSEPH TO BOONVILLE
BOONVILLE TO MOUTH
AVERAGE VELOCITY - FEET PER SECOND
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
5
10
15
20
25
30
35
40
45
50
DISCHARGE IN 1000 C.F.S.

Table 11 Missouri River Investigation - Average of January and February, 1940,* Mean Monthly Discharges in Cubic Feet per Second.

Gaged Flow of Missouri River		Gaged Inflow from Major Tributaries		Indicated Incremental Inflow from Minor Tributaries
Station	Discharge	Stream	Discharge	
Yankton	4,670			
		--	--	Negligible
Sioux City	4,660			
		--	--	Negligible
Omaha	4,690			
		Platte River	1,810	Negligible
Nebraska City	6,560			
		--	--	150
St. Joseph	6,710			
		Kansas River	600	Negligible
Kansas City	7,160			
		--	--	Negligible
Waverly	7,120			
		Grand River	90	100
Boonville	7,310			
		Osage River	780	700
		Gasconade River	760	
Hermann	9,550			

* Two-month period of lowest flows for the River as a whole within the period of records.

Note: No adjustment has been made for the influence of time of travel in determining the above "Indicated Incremental Inflow from Minor Tributaries."

U. S. Engineer Office,
Omaha, Nebraska,
December, 1942.

Table 12 Missouri River Investigation - Monthly Mean Winter Flows for Years in Which Lowest Winter Flows Have Occurred.

River Location	Missouri Yankton, S. Dak.	Missouri Omaha, Nebraska	Missouri St.Joseph, Missouri	Missouri Kansas City, Mo.
Miles Above Mouth	849.3	637.2	461.4	380.5
Drain.Area Sq.Mi.	269,000	322,800	424,300	489,200
Year 1934-1935				
December c.f.s.	5,742	6,121	8,919	11,130
January "	5,606	5,823	8,241	9,175
February "	10,480	10,510	17,390	19,110
Year 1937-1938				
December c.f.s.	5,196	5,158	7,600	7,906
January "	7,074	6,801	10,680	11,460
February "	7,061	8,982	13,110	14,350
Year 1939-1940				
December c.f.s.	10,150	11,020	13,780	14,790
January "	3,760	3,706	5,026	5,010
February "	5,572	5,679	8,400	9,308

River Location	Missouri Boonville, Missouri	Platte Ashland, Nebraska	Kansas Bonner Spgs. Kans.	Grand Sumner, Missouri
Mouth to Mouth of Missouri River	199.4	613	381.9	255
Drain.Area Sq.Mi.	505,700	83,800	59,890	6,880
Year 1934-1935				
December c.f.s.	23,120	1,787	1,800	3,446
January "	15,840	2,333	1,220	1,892
February "	27,650	5,396	890	3,096
Year 1937-1938				
December c.f.s.	12,610	2,936	637	85
January "	13,680	3,912	807	102
February "	61,300	2,580	1,060	131
Year 1939-1940				
December c.f.s.	15,560	2,028	588	67
January "	4,919	1,268	408	32
February "	9,693	2,357	798	142

Table 13 Missouri River Investigation - Monthly Mean Summer Flows for Years in Which Lowest Summer Flows have Occurred.

River Location	Missouri Yankton, S. Dak.	Missouri Omaha, Nebraska	Missouri St.Joseph, Missouri	Missouri Kansas City, Mo.
Miles Above Mouth	849.3	637.2	461.4	380.5
Drain.Area Sq.Mi.	269,000	322,800	424,300	489,200
Year 1931				
June c.f.s.	31,900	32,000	38,900	43,100
July "	21,000	22,900	29,300	34,000
August "	10,800	11,200	13,900	19,800
September "	8,320	9,700	15,800	24,000
Year 1934				
June c.f.s.	29,810	31,980	35,540	38,240
July "	18,900	22,900	26,250	28,210
August "	9,035	9,981	11,680	12,480
September "	6,818	7,350	11,040	13,200
Year 1937				
June c.f.s.	56,240	56,710	58,680	61,210
July "	48,300	52,590	61,980	69,770
August "	15,710	22,870	29,520	34,870
September "	8,054	9,093	12,990	15,370
Mean of Record	20,607	23,462	27,732	36,247

River Location	Missouri Boonville Missouri	Platte Ashland Nebraska	Kansas Bonner Spgs.Kans.	Grand Sumner Missouri
Mouth to Mouth of Missouri River	199.4	613	381.9	255
Drain.Area Sq.Mi.	505,700	83,800	59,890	6,880
Year 1931				
June c.f.s.	52,300	3,790	4,640	4,230
July "	36,300	1,910	3,120	452
August "	21,900	1,740	5,020	335
September "	31,300	2,340	6,860	5,100
Year 1934				
June c.f.s.	37,210	2,847	2,883	308
July "	30,220	1,473	1,180	53
August "	14,320	1,532	455	214
September "	17,810	2,183	1,518	1,269
Year 1937				
June c.f.s.	60,790	4,943	5,278	1,649
July "	78,380	2,449	3,772	2,820
August "	39,810	1,934	3,101	493
September "	17,480	2,125	1,893	93
Mean of Record	46,109	4,674	4,506	3,186

Table 14 Missouri River Investigation - Frequency of Low Mean Monthly Winter and Midwinter Discharges in Missouri River at Points from Fort Randall, S. D., to Below Kansas City.

Location	Frequency - Once in:				
	2 Years	3 Years	5 Years	10 Years	Minimum
Winter - December to February					
Yankton, S.D.	6,500	6,200	5,500	4,700	3,800
Omaha, Nebr.	6,600	6,200	5,600	4,900	3,700
Nebraska City	8,800	7,600	7,300	6,200	5,000
St. Joseph, Mo.	10,000	8,200	7,700	6,400	5,000
Kansas City	10,200	9,100	7,800	6,800	5,000
Midwinter - January					
Yankton, S. D.	7,100	7,000	6,400	5,200	3,800
Omaha, Nebr.	7,500	6,800	6,200	5,300	3,700
Nebraska City	11,000	9,600	7,500	6,200	5,000
St. Joseph, Mo.	12,500	10,200	8,000	6,400	5,000
Kansas City	14,600	10,200	9,000	6,800	5,000

Ice Cover

The question of ice cover has been given considerable attention, with the thought that winter conditions under ice may be the most critical from a pollution standpoint, as during the period of "complete" ice cover the river water is deprived of its principal source of oxygen, atmospheric reaeration. However, while there may be a considerable reduction in reaeration, the evidence indicates that ice cover has not caused dissolved oxygen to approach total depletion in the past. The points in evidence are as follows:

(1) The few available Missouri River laboratory results on samples collected under ice do not show abnormally low dissolved oxygen.

(2) Neither the various State fisheries organizations nor the U. S. Fish and Wildlife Service have reports of fish killings under ice in the Missouri River, such as would be expected if dissolved oxygen approached total depletion.

(3) Missouri River water supplies report no taste and odor troubles during the period of ice cover, which might be expected with water low in or devoid of oxygen.

A possible explanation of the apparent lack of critical importance of the period of ice cover is the fact that ice cover on the Missouri River is never really "complete." There may be a great difference between a river so covered and one which has occasional open spots at riffles or at eddies. Furthermore, while a small stream may have an ice cover with sufficient structural strength to make the channel virtually a closed pipe, this is not possible in a stream as large as the Missouri River. The ice cover on a large stream must rise and fall with minor flow variations and is subject to constant alternate cracking and drawing away from the banks.

With respect to ice cover, an important consideration is the fact that the most highly polluted section of the Missouri River, below Kansas City, has frozen but twice for brief periods in a record of forty years and, on these two occasions, Weather Bureau observer comments appear to indicate that the cover was not "complete."

The results of a review of U. S. Weather Bureau ice records indicate that the average periods of ice cover are 88 days (December 11 to March 9) at Sioux City, 52 days (December 29 to February 18) at Omaha, and negligible at Kansas City. However, the time between the freeze and the breakup may not be as important as data on the completeness of ice cover. Such data are not extensive. Comments by the U. S. Weather Bureau ice observer furnish the only record that is at all systematic. Thus, while at Omaha the average period of ice cover is 52 days, the average period when the observer considered it practical to make ice measurements was only 24 days and the average continuous such period was 18 days. Reasons mentioned include "open water along shore" and "ice unsafe." It is usual for the observer merely to report that it was impractical to make an ice measurement. However, observers are instructed not to take chances, and often the ice may be considered unsafe due to a cracked condition. Crossing the Missouri River on the ice is considered hazardous, and serious accidents have been reported.

The Red River of the North Report (Bibliography (2)) presents the only record located of dissolved oxygen under ice in the Missouri River. The samples were collected at Bismarck, North Dakota. Relative to ice cover, the report states, "However, portions of the river remain open during moderately severe sub-zero weather because of swift currents."

There apparently was a freeze of the Missouri at Kansas City in January, 1943, as evidenced by a photograph published in the Kansas City Times of January 22, 1943, under the caption "The 'Big Muddy' Goes Solid Again." However, the explanation under the phorograph states that "Recent cold weather converted the surface of the Missouri River into solid ice at many places in its course past Kansas City. This view is looking east toward the A.-S.-B. bridge from the Hannibal bridge. The eddies caused by the Hannibal bridge abutments and the river's rapid current are shown here to have caused some open water to remain, but the ice is solid from the north to the south bank in places."

Winter Flow Requirements

In determining necessary minimum discharges for pollution control, two situations are to be considered. In the first situation, there is an excess of dilution water available at all times over and above that required to assimilate existing pollution loads without damage to present and reasonable future stream uses. It is therefore necessary to determine the magnitude of the flow required at various temperatures in order that there shall continue to be no damage. Such situations are in the minority.

In the second and more common situation, pollution is of such magnitude that present and reasonable future stream uses are suffering damage to some degree, particularly during months of critical low flows and to a lesser degree during moderate flows. In such a situation the chief objective is to so regulate the flow in the stream that the year-around condition of the stream is not degraded but at least maintained in its present condition and preferably improved during the worst months. In other words, critical low flows can be augmented to compensate for reduction in the higher flows.

The Ft. Randall Dam project fits in well with the improvement of pollution conditions in that it contemplates reducing the flow in winter when flow requirements for pollution control are at a minimum and increasing the flow during the navigation season including midsummer, when flow requirements for pollution control are at a maximum.

The investigation has been fortunate in having the results of a short time but concentrated winter laboratory study of the critical stretch of the Missouri River immediately above and extending some distance below Kansas City. Moreover, the results show a rise in biochemical oxygen demand (B.O.D.) in passing Kansas City (Table 10) which checks very well with what might be expected from a knowledge of the magnitude of Kansas City pollution. This is followed by a regular drop in the B.O.D. as the demand is satisfied by the dissolved oxygen of the stream. The oxygen results show a regular though shallow sag in the dissolved oxygen below the city, followed by a recovery farther down the stream.

With the help of these winter results, it has been possible to derive deoxygenation and reaeration constants for the Missouri River at temperatures near the freezing point

and then compute the minimum dissolved oxygen to be expected with various flows and under various percentages of ice cover. Such computations can be and have been made with a degree of assurance, so that the principal point in question and one which will determine flow requirements, is the per cent of ice cover to be expected during an average and during a severe winter.

Rather than attempt to estimate the extent of ice cover from rather unsatisfactory base data, a flow has been taken from a study of the frequency of low winter flows in the past, and fairly thorough computations have been made of the amount of ice cover which will permit dissolved oxygen to be maintained at various oxygen levels. The results of this approach are summarized as Conclusion (7).

The low winter monthly flow of 5,500 c.f.s. at Yankton has occurred, in the past, once every five years, and has occurred somewhat less frequently during the critical midwinter month of January. The flow is 40 per cent in excess of the minimum average monthly flow and 90 per cent in excess of the minimum average daily flows.

Table 15 presents a summary of flow increases which will result from proposed stream regulation. The minimum monthly winter flow will b e increased 18 per cent of the years, the increase will amount to 1,000 c.f.s. 8 per cent of the years, and the maximum increase will be 1,700 c.f.s. In summer, the minimum monthly flow will be increased 77 per cent of the years, the increase will amount to 10,000 c.f.s. 28 per cent of the years, and the maximum increase will be 13,200 c.f.s.

Should a severe winter result in more complete ice cover than shown on Conclusion (7), there remains the possibility of artificially opening the river by fluctuating the flow. This suggestion is not based on precedent, as no record of the use of such a practice has been found. Rather, it is based on an observation of the U. S. Weather Bureau ice data, where numerous occasions are recorded where one week as much as 24 inches of ice may be found, while the following week open water along the shore, a cracked condition or unsafe ice may be reported.

Table 15 Missouri River Investigation - Frequency of Minimum Flow Increases at Yankton, S. D., with 20,000 c.f.s. Release in Summer and 5,500 c.f.s. Release in Winter.

Mean Monthly Flow Increase Cubic Feet per Second	Per Cent of Years Increase Occurs			
	With 20,000 c.f.s. at Yankton		With 5,500 c.f.s. at Yankton	
	Summer June to September	Midsummer July and August	Winter December to February	Midwinter January
1	77	63	18	12
1,000			8	7
1,700			4	4
2,000	73	52		
4,000	67	41		
6,000	58	30		
8,000	43	20		
10,000	28	8		
10,900		4		
12,000	13			
13,200	4			

The sequence of circumstances required for the formation of an ice "gorge" has not been investigated. Any fluctuation of flow tending to create an ice "gorge" is to be avoided, and presumably the possibility of creating this or other dangerous ice conditions will be investigated.

Flow requirements as set forth in this report are intended for use in preliminary engineering and economic studies. As such, they are believed reliable. However, with experience in operation, there is a possibility that flow adjustments may be permitted downward or required upward. An organization accepting the responsibility of regulating the flow in a stream presumably will maintain a record of pollution as well as other conditions in order that the natural waters may be used to best advantage of all concerned.

While the Missouri is only moderately polluted, conditions are not satisfactory, nor will they be satisfactory after summer flows are increased to provide for navigation requirements. As long as raw sewage in quantity is discharged, sludge deposits will form and create objectionable conditions, particularly in the vicinity of outlets. Therefore, treatment of sewage and correction of industrial wastes is a future probability. At that time flow regulation will have value as a supplementary measure to sewage treatment and industrial waste treatment or corrective measures. Another possibility is a high degree of treatment, permitting possible further decrease in seasonal flows.

Bibliography

(1) Hygienic Laboratory Bulletin No. 89, U. S. Public Health Service, May, 1913, "Sewage Pollution of Interstate and International Waters with Special Reference to the Spread of Typhoid Fever. VI. The Missouri River from Sioux City to Its Mouth," by Allan J. McLaughlin, Passed Assistant Surgeon.

(2) "Red River of the North Research Investigation 1938-1941," Division of Sanitary Engineering, North Dakota State Department of Health.

(3) "Study of the Sanitary Condition of the Missouri River in the Kansas City District," by Morris B. Ettinger, Assistant Sanitary Chemist, U.S.Public Health Service, January, 1943. (Unpublished: see Appendix "A").

(4) "Census of Water Treatment Plants" 1941, Stream Pollution Investigations Station, U. S. Public Health Service.

(5) "Census of Sewer Systems and Sewage Treatment Plants" 1941, Stream Pollution Investigations Station,U.S.Public Health Service.

(6) "Dissolved Oxygen Content of Missouri River Water, 1933-1942." Data assembled by Water Quality Laboratories, U.S.Fish & Wildlife Service, Columbia,Missouri, Dr.M.M.Ellis, Senior Aquatic Biologist, in Charge. (Unpublished: see Appendix "B").

(7) U.S.Engineers Report on Missouri River. House Document No.238, 73d Congress, 2d Session. Government Printing Office 1935.

(8) "Surface Water Supply of the United States, Part 6, Missouri River Basin," Geological Survey Water-Supply Papers, U. S. Department of the Interior.

(9) Unpublished preliminary discharge records on Missouri and Kansas Rivers, December, 1942, - Subject to Correction - Geological Survey, U. S. Department of the Interior.

(10) "16th Census of the United States, 1940, Population, First Series, Number of Inhabitants." U.S.Department of Commerce.

(11) Published and unpublished records of the Weather Bureau, U. S. Department of Commerce.

(12) Monthly "Service and Regulatory Announcements," Bureau of Animal Industry, U. S. Department of Agriculture.

(13) Unpublished municipal records of water temperatures and coliform results.

(14) Published reports and unpublished records of local Chambers of Commerce.

MISSOURI RIVER INVESTIGATION

A P P E N D I X "A"

Study of the Sanitary Condition of the Missouri River in the Kansas City District

by

Morris B. Ettinger
Assistant Sanitary Chemist

Federal Security Agency
U. S. PUBLIC HEALTH SERVICE
Stream Pollution Investigations
Cincinnati, Ohio
January, 1943

PROJECT REPORT
STUDY OF SANITARY CONDITION OF THE MISSOURI RIVER IN THE KANSAS CITY DISTRICT

For this study the trailer laboratory was located in Independence, Missouri. The period December 10 to December 29 was devoted to this work.

The primary object of this work was to determine existing stream conditions in the Missouri River so that its potential ability to handle further pollutional loads might be estimated. Further pollutional loads contemplated include the effluent from a grain alcohol plant to be located at Kansas City. The immediate issue concerns whether a waste disposal system for the plant is absolutely essential in order that the Missouri River may meet minimal requirements of stream sanitation in the region below Kansas City.

The project was undertaken at the suggestion of the Missouri State Health Department and details of the points to be sampled and the essential data were largely decided by Mr. Kehr of the Missouri State Health Department. A good measure of assistance in sampling was obtained from Missouri personnel. Mr. Brazee and Mr. Carl, respectively of the Central office and Jackson County, were in no small measure responsible for successful execution of a difficult sampling schedule in a relatively brief period.

In all, 111 samples were collected. Of these samples, 20 were taken from the Kansas River, the rest being Missouri River samples. Examinations made consisted of B.O.D., Alkalinity, and/or pH on composite samples at any given cross section with M.P.N. and D.O. at individual points. The samples, taken off high bridges, were of necessity taken fairly shallow and at no particular depth. In general, samples were taken from 6" to 3' below the surface. All samples were taken from Highway bridges.

Compilation of analytical results follows. In examination of analytical results, certain features of the table should be kept in mind:

(1) M.P.N. is reported as M.P.N. per 100 ml.
(2) B.O.D., pH and Alkalinity results are the result of examinations of composite samples where more than one sample was taken at a given section. They are, however, reported with data from each section (i.e., R., C., L.).

During the work on this project the trailer was used at considerably over 100% of capacity. A large number of 15-hour days and Saturdays and Sundays were put in by various members of the trailer crew.

Date	No.	pH	Alka-linity	Temp. °C.	D.O.	% Satu-ration	B.O.D.	M.P.N./100 ml.
Kansas River Above Kansas City (K-1) - Kansas Ave.								
12/14/42	14	8.2		4-1/2	14.28	110.1	5.48	7500
12/15	26	8.1	304.3	2	13.31	94.7	2.66	2300
12/16	44	8.3		1/2	13.61	94.3	3.52	15000
12/17	56	8.2		4	12.96	98.7	3.32	7500
12/23	95	8.2		3	13.32	98.8	2.67	2300
Kansas River at Kansas City (K-2) Left Side - Intercity Viaduct								
12/14	15	8.3		2	13.79	99.6	17.88	
12/15	29	8.1	286.2	2	12.88	93.06	16.68	
12/16	47	8.3		1/2	12.86	89.1	27.50	
12/17	59	8.0		4	12.62	96.1	15.66	
12/23	98	8.1		1-1/2	13.08	93.1	9.90	
Kansas River at Kansas City (K-2) Center								
12/14	16	8.3		2	13.68	98.8	17.88	
12/15	28	8.1	286.2	1-1/2	12.82	91.3	16.68	
12/16	46	8.3		1/2	12.91	89.4	27.50	
12/17	58	8.0		3-1/2	12.81	96.2	15.66	
12/23	97	8.1		1	13.05	91.7	9.90	
Kansas River at Kansas City (K-2) Right Side								
12/14	17	8.3		1	14.46	101.6	17.88	
12/15	27	8.1	286.2	1	14.64	102.8	16.68	
12/16	45	8.3		1/2	12.77	88.4	27.50	
12/17	57	8.0		3-1/2	12.45	93.5	15.66	
12/23	96	8.1		1	12.88	90.5	9.90	
Missouri River Above Kansas City (M-2) Right Side U.S. 69-169								
12/14	19	7.9		4	13.72	104.4	5.54	9300
12/15	30	7.9	260.9	7	12.72	104.5	2.94	46000
12/16	48	8.0		1/2	12.93	89.6	3.92	9300
12/17	60	7.9		3	12.51	92.8	2.48	24000
12/23	99	7.9		1-1/2	12.65	90.1	3.21	15000
Missouri River Above Kansas City (M-2) Left Side								
12/14	18	7.9		4	13.79	105.02	5.54	7500
12/15	31	7.9	260.9	2	12.92	93.4	2.94	9300
12/16	49	8.0		1/2	12.78	88.5	3.92	24000
12/17	61	7.9		2-1/2	12.47	83.9	2.48	15000
12/23	100	7.9		1	12.91	90.7	3.21	46000

Date	No.	pH	Alka-linity	Temp. °C.	D.O.	% Satu-ration	B.O.D.	M.P.N./100 ml.
Missouri R.at Kansas City(M-3)R.Side-U.S.71 K.C.to North K.C. Br.								
12/14/42	22	7.9		1-1/2	13.66	97.2	6.05	240,000
12/15	32	7.9	266.7	1	12.20	86.3	6.65	240,000
12/16	50	8.0		1/2	12.26	84.9	7.51	240,000
12/17	62	8.0		3	12.79	87.4	6.19	75,000
12/23	101	7.8		1	12.75	89.6	5.45	93,000
Missouri River at Kansas City (M-3) Center								
12/14	21	7.9		2	13.80	99.6	6.05	240,000
12/15	33	7.9	266.7	1	12.79	89.8	6.65	43,000
12/16	51	8.0		1/2	12.84	88.9	7.51	43,000
12/17	63	8.0		3-1/2	12.62	94.8	6.19	150,000
12/23	102	7.8		1	12.76	89.7	5.45	75,000
Missouri River at Kansas City (M-3) Left Side								
12/14	20	7.9		4-1/2	13.84	106.7	6.05	4,300
12/15	34	7.9	266.7	1-1/2	12.78	91.02	6.65	23,000
12/16	52	8.0		1/2	12.79	88.6	7.51	23,000
12/17	64	8.0		4-1/2	12.80	98.7	6.19	64,000
12/23	103	7.8		1-1/2	12.80	91.1	5.45	93,000
Missouri River Below Kansas City (M-4) Right Side - Bypass U.S.71								
12/14	25	7.9		5	12.99	101.4	5.29	39,000
12/15	35	7.8	279.7	2-1/2	12.35	90.4	8.92	23,000
12/16	53	7.8		1/2	12.58	86.4	4.59	93,000
12/18	71	7.9		3	11.89	88.2	5.31	43,000
12/20	80	8.1		0	13.26	90.7	5.55	23,000
Missouri River Below Kansas City (M-4) - Center								
12/14	24	7.9		3-1/2	13.05	98.04	5.29	75,000
12/15	36	7.8	279.7	1-1/2	12.31	87.6	8.92	43,000
12/16	54	7.8		1/2	12.62	87.3	4.59	23,000
12/18	72	7.9		2-1/2	12.17	89.09	5.31	43,000
12/20	81	8.1		0	13.14	89.9	5.55	75,000
Missouri River Below Kansas City (M-4) - Left Side								
12/14	23	7.9		2-1/2	13.53	99.04	5.29	23,000
12/15	37	7.8	279.7	1-1/2	11.15	79.4	8.92	93,000
12/16	55	7.8					4.59	93,000
12/18	73	7.9		2	12.13	87.6	5.31	43,000
12/20	82	8.1		0	12.95	88.5	5.55	39,000

Date	No.	pH	Alka-linity	Temp. °C.	D. O.	% Satu-ration	B.O.D.	M.P.N./100 ml.
Missouri River at Lexington - Right Side - M-5)								
12/11/42	11			2-1/2	12.72	93.1		24,000
12/15	38			1	12.35	86.7	6.03	23,000
12/17	65	7.9		2	12.36	89.3	5.36	43,000
12/18	74	7.8		1	12.08	84.8	4.33	43,000
12/20	83	8.1		0	12.60	86.2	7.64	150,000
12/22	89	7.9		1-1/2	12.13	86.4	5.28	93,000
Missouri River at Lexington - Center - (M-5)								
12/11	12			2-1/2	12.28	89.1		110,000
12/15	39			1	12.11	85.1	6.03	23,000
12/17	66	7.9		2	12.29	88.8	5.36	43,000
12/18	75	7.8		1/2	11.93	82.5	4.33	9,100
12/20	84	8.1		0	12.74	87.1	7.64	93,000
12/22	90	7.9		1-1/2	12.29	87.5	5.28	43,000
Missouri River at Lexington - Left Side - (M-5)								
12/11	13			2-1/2	12.28	89.1		24,000
12/15	40			2	12.22	88.3	6.03	14,000
12/17	67	7.9		4	12.29	93.6	5.36	43,000
12/18	76	7.8		2	11.95	86.3	4.33	23,000
12/20	85	8.1		0	12.68	86.7	7.64	43,000
12/22	91	7.9		1-1/2	12.38	88.2	5.28	43,000
Missouri River at Waverly - (M-6) - Right Side								
12/11	9			2-1/2	11.51	84.2		
12/15	41			2	12.50	90.3	4.64	43,000
12/17	68	7.8		2-1/2	11.93	87.3	7.34	240,000
12/18	77	7.9		1-1/2	11.63	82.8	6.36	43,000
12/20	86	8.1		0	12.38	84.6	6.70	93,000
12/22	92	8.0		2-1/2	12.86	92.6	3.75	43,000
Missouri River at Waverly - (M-6) - Center								
12/15	42			1-1/2	12.50	89.04	4.64	43,000
12/17	69	7.8		2	11.85	85.6	7.34	23,000
12/18	78	7.9		1-1/2	11.48	81.7	6.36	23,000
12/20	87	8.1		0	12.45	85.1	6.70	39,000
12/22	93	8.0		3	12.88	95.5	3.75	23,000
Missouri River at Waverly - (M-6) - Left Side								
12/11	10			3-1/2	12.63	94.8		
12/15	43			1-1/2	12.38	88.2	4.64	150,000
12/17	70	7.8		2-1/2	10.62	77.7	7.34	93,000
12/18	79	7.9		0	11.52	78.7	6.36	240,000
12/20	88	8.1		0	12.40	84.8	6.70	150,000
12/22	94	8.0		2	12.63	91.2	3.75	93,000

Date	No.	pH	Alka-linity	Temp. °C.	D. O.	% Satu-ration	B.O.D.	M.P.N./100 ml.
Missouri River at Miami (M-7) - Right Side - Mo. 41								
12/11/42	7			3	12.58	93.3		
12/26	104			3	11.38	84.4		
Missouri River at Miami - (M-7) - Left Side								
12/11	8			3	12.74	94.5		
12/26	105			4	11.96	91.1		
Missouri River at Glasgow - (M-8) - Right Side								
12/11	5			2-1/2	12.85	94.07		
12/26	106			6	11.82	94.7		
Missouri River at Glasgow - (M-8) - Left Side								
12/11	6			3	12.98	96.2		
12/26	107			6	11.91	95.4		
Missouri River at Booneville - (M-9) - Right Side								
12/11	3			3	13.05	96.7		
12/26	108			5-1/2	12.00	94.8		
Missouri River at Booneville - (M-9) - Left Side								
12/11	4			3	12.72	94.3		
12/26	109			7	12.08	99.3		
Missouri River at Jefferson City - (M-10) - Right Side								
12/11	1			1-1/2	13.25	94.3		
12/26	110			6	12.20	97.8		
Missouri River at Jefferson City - (M-10) - Left Side								
12/11	2			1-1/2	13.15	93.6		
12/26	111			6	12.12	97.1		

MISSOURI RIVER INVESTIGATION

A P P E N D I X "B"

Dissolved Oxygen Content of Missouri River Water, 1933-1942

M. M. Ellis, Ph.D., Sc.D.
Senior Aquatic Biologist.

Department of the Interior
FISH AND WILDLIFE SERVICE
Water Quality Laboratories
Columbia, Missouri
January, 1943.

DISSOLVED OXYGEN CONTENT MISSOURI RIVER WATER 1933-1942.*

Data Assembled by Water Quality Laborat ories, U.S. Fish and Wildlife Service, Columbia, Missouri.

Month	Blair Nebraska				Nebraska City Nebraska				Below Kansas City, Missouri				Boonville Missouri				St. Charles Missouri			
	Minimum	Average	Maximum	Number of Cases	Minimum	Average	Maximum	Number of Cases	Minimum	Average	Maximum	Number of Cases	Minimum	Average	Maximum	Number of Cases	Minimum	Average	Maximum	Number of Cases
Jan.	8.6	8.8	9.0	3	7.6	7.8	7.9	3	2.1	4.4	8.0	16	6.8	7.3	7.6	4	6.6	6.9	7.1	4
Feb.	8.0	8.2	8.4	4	6.0	7.3	8.0	4	3.6	4.9	7.1	3	5.4	6.8	8.3	12	6.0	6.5	7.2	7
March	8.0	8.4	8.9	4	7.0	7.5	8.0	4	3.2	4.7	6.4	4	6.1	6.9	7.4	9	6.4	6.9	7.1	4
April	8.0	8.3	8.6	2	7.3	7.4	7.4	2	2.1	3.7	5.1	6	6.2	6.7	7.1	5	6.8	6.9	7.1	3
May	7.6	7.7	7.8	2	6.0	6.1	6.1	2	2.1	4.1	6.1	10	5.6	6.3	7.1	8	4.8	6.1	6.9	6
June	7.8	7.9	7.9	2	5.6	5.9	6.1	2	2.7	4.0	6.1	10	5.2	5.5	6.0	8	4.8	5.7	6.1	5
July	6.9	7.5	8.0	2	4.6	5.0	5.4	2	2.1	3.7	4.6	11	4.2	5.0	5.9	6	4.8	5.5	6.1	4
Aug.	6.4	6.9	7.4	2	4.8	4.9	5.0	2	2.7	3.7	6.1	11	4.2	5.1	5.7	8	3.8	4.6	6.1	5
Sept.	6.2	6.9	7.2	4	4.3	5.6	7.0	4	2.9	4.5	6.8	11	4.4	5.2	6.1	7	4.8	5.1	5.8	4
Oct.	7.1	7.2	7.4	3	5.2	5.7	6.1	3	2.8	3.8	4.6	7	5.1	6.2	7.1	8	5.8	5.9	6.0	2
Nov.	8.9	9.0	9.1	3	8.9	9.0	9.0	3	3.6	4.2	4.8	7	5.1	6.9	8.2	11	7.0	7.4	7.8	2
Dec.	8.9	9.1	9.2	3	7.8	8.1	8.6	3	3.8	4.7	6.2	3	6.1	7.4	8.3	9	6.0	7.1	8.0	4
	7.1	8.0	9.2	34	4.3	6.7	9.0	34	2.1	4.2	8.0	99	4.2	6.3	8.3	95	3.8	6.2	8.0	50

* See individual station tables for exact dates of samplings.

DISSOLVED OXYGEN IN MISSOURI RIVER WATER
BLAIR, NEBRASKA, STATION

Data Assembled by Water Quality Laboratories
U.S. Fish and Wildlife Service, Columbia, Missouri

Date	Water Temperature °C.	Dissolved Oxygen Parts per Million	Date	Water Temperature °C.	Dissolved Oxygen Parts per Million
Jan. 4, 1938	4.1	9.0	July 6,1938	19.0	8.0
" 12, 1939	6.0	8.9	" 12,1940	21.0	6.9
" 20, 1940	3.8	8.6	Aug. 6, 1939	22.0	7.4
Feb. 6, 1937	5.1	8.2	" 14, 1940	22.1	6.4
" 12, 1938	4.6	8.4	Sept.20 ,1937	18.0	7.2
" 22, 1939	5.2	8.0	" 12,1938	21.0	7.0
" 10, 1940	6.0	8.1	" 16,1939	22.0	7.1
Mar. 3, 1937	6.2	8.4	" 4,1940	21.0	6.2
" 11, 1938	5.9	8.4	Oct. 3, 1938	17.0	7.4
" 22, 1939	7.8	8.0	" 21, 1939	18.0	7.1
" 24, 1940	6.8	8.9	" 30, 1940	14.0	7.2
Apr.10, 1938	10.0	8.0	Nov.21, 1934	7.4	9.1
" 20, 1940	8.1	8.6	" 20, 1938	8.2	8.9
May 16, 1937	15.0	7.8	" 30, 1940	8.4	8.9
" 20, 1939	17.0	7.6	Dec. 6, 1938	4.0	8.9
June 12,1938	18.4	7.9	" 12, 1940	4.0	9.1
" 30,1940	18.6	7.8	" 20, 1940	3.9	9.2

DISSOLVED OXYGEN IN MISSOURI RIVER WATER
NEBRASKA CITY, NEBRASKA STATION

Data Assembled by Water Quality Laboratories
U.S.Fish and Wildlife Service, Columbia, Missouri

Date	Water Temperature °C.	Dissolved Oxygen Parts per Million	Date	Water Temperature °C.	Dissolved Oxygen Parts per Million
Jan. 5,1938	4.2	7.8	July 8,1938	22.0	5.4
" 13,1939	6.0	7.9	" 12,1940	22.0	4.6
" 20,1940	4.0	7.6	Aug. 8,1939	23.1	5.0
Feb. 7,1937	6.1	7.0	" 16,1940	21.1	4.8
" 12,1938	4.8	8.0	Sept.20,1937	18.0	7.0
" 24,1939	5.8	6.0	" 14,1938	20.0	5.0
" 10,1940	7.1	8.0	" 16,1939	22.0	5.9
Mar. 3,1937	5.0	8.0	" 4,1940	21.6	4.3
" 14,1938	6.0	7.0	Oct. 6,1938	16.4	5.9
" 24,1939	7.1	8.0	" 23,1939	17.0	5.2
" 26,1940	6.0	7.1	" 28,1940	13.9	6.1
Apr.10,1938	9.6	7.3	Nov.24,1934	8.3	8.9
" 21,1940	7.9	7.4	" 22,1938	8.0	9.0
May 18,1937	17.0	6.1	" 28,1940	8.0	8.9
" 24,1939	19.0	6.0	Dec. 8,1938	4.2	7.8
June 14,1938	20.0	5.6	" 14,1940	4.0	8.6
" 28,1940	20.2	6.1	" 22,1940	3.8	8.0

DISSOLVED OXYGEN IN MISSOURI R. WATER AT STATIONS IN THE FIRST 12 MILES SECTOR DOWNSTREAM FROM THE NORTH KANSAS CITY BRIDGE, KANSAS CITY, MISSOURI

Data Assembled by Water Quality Laboratories
U.S. Fish & Wildlife Service, Columbia, Missouri

Date	Water Temperature °C.	Dissolved Oxygen Parts per Million
Jan. 4, 1933	4.6	7.6
" 12, 1934	6.1	2.1
" 16, 1935	5.6	3.1
" 16 "	5.4	6.1
" " "	6.0	3.6
" 22, 1938	5.3	3.7
" " "	5.7	6.6
" " "	6.4	7.1
" " "	5.4	3.2
" 30, 1939	4.6	8.0
" " "	4.9	3.0
" " "	5.2	2.1
" 12, 1940	6.1	2.3
" " "	4.4	3.1
" " "	5.1	3.4
" " "	5.9	6.4
Feb. 6, 1934	6.8	7.1
" 14, 1938	7.0	4.1
" 18, 1940	6.2	3.6
Mar. 17, 1936	8.1	5.1
" 20, 1938	8.3	3.2
" 19, 1940	7.9	6.4
" 3, 1941	10.6	4.1
Apr. 10, 1934	12.1	4.1
" 6, 1936	15.0	3.4
" " "	15.3	5.1
" " "	16.2	3.4
" " "	15.9	4.1
" " "	16.1	2.1
May 5, 1938	19.1	3.7
" " "	19.6	4.1
" " "	19.3	2.1
" " "	19.7	6.1
" " "	20.1	5.1
" 22, 1939	21.2	3.4
" " "	21.3	3.8
" " "	20.9	4.1
" " "	20.8	3.9
" " "	21.1	4.2
June 14, 1938	23.6	4.1
" " "	23.0	3.9
" " "	24.1	3.4
" " "	23.9	6.1
" " "	23.4	4.3
" " "	24.3	3.9
" " "	24.1	4.0
" " "	23.9	2.7
" 20, 1939	25.4	3.8
" " "	25.2	4.1
July 7, 1935	26.0	4.2
" " "	26.2	4.3
" " "	25.8	4.6
" 15, 1938	24.9	3.2
" " "	25.0	4.6
" " "	25.3	2.1
" " "	24.8	2.9
" 20, 1940	25.3	4.0
" " "	26.0	3.7
" " "	25.9	2.4
" " "	25.8	4.6
Aug. 12, 1936	24.0	6.1
" " "	24.6	2.9
" " "	24.9	3.3
" " "	25.0	3.6
" 28, 1938	26.2	3.8
" " "	26.6	4.4
" " "	26.6	5.1
" " "	27.0	2.9
" 30, 1940	26.6	3.1
" " "	24.0	3.0
" " "	24.6	2.7
Sept. 3, 1935	21.4	4.6
" " "	20.9	4.0
" 12, 1938	19.6	4.0
" " "	19.0	3.8
" " "	19.4	6.8
" " "	19.0	5.4
" 22, 1940	20.1	5.4
" " "	20.0	5.2
" " "	20.2	3.9
" " "	20.4	3.1
" " "	21.0	2.9
Oct. 7, 1934	14.0	4.6
" 18, 1937	15.2	4.0
" 22, 1938	14.4	3.8
" " "	14.6	3.9
" " "	14.9	4.0
" " "	14.2	2.8
" " "	14.8	3.7
Nov. 4, 1935	8.2	4.4
" 8, 1938	9.1	4.4
" 12 "	7.1	4.6
" " "	7.2	4.8
" " "	6.9	3.9
" " "	7.1	3.6
" " "	8.0	4.0
Dec. 20, 1937	6.1	4.1
" " "	4.7	3.8
" 22, 1938	4.3	6.2

DISSOLVED OXYGEN IN MISSOURI RIVER WATER
BOONVILLE, MISSOURI, STATION
Data Assembled by Water Quality Laboratories
U.S.Fish & Wildlife Service, Columbia, Missouri

Date	Water Temperature °C.	Dissolved Oxygen Parts per Million	Date	Water Temperature °C.	Dissolved Oxygen Parts per Million
Jan.20,1934	5.1	7.4	July 6,1933	22.3	5.9
" 30,1936	6.0	7.4	" 8,1935	24.0	5.2
" 26,1938	5.2	6.8	" 10,1937	23.0	5.1
" 10,1940	8.0	7.6	" 20,1939	24.0	5.0
Feb. 6,1933	7.0	6.4	" 6,1940	23.0	4.2
" 12,1935	8.0	6.2	" 18,1941	26.0	4.8
" 14,1936	5.9	7.1	Aug. 6,1933	23.0	4.2
" 12,1937	5.0	6.2	" 3,1935	24.1	4.9
" 18,1938	6.2	8.1	" 12,1936	26.0	5.2
" 20,1939	6.1	8.3	" 22,1937	24.0	5.1
" 6,1940	5.2	7.1	" 6,1939	22.6	5.4
" 4,1941	6.3	6.1	" 14,1940	23.4	5.7
" 6,1942	5.3	6.0	" 17,1941	22.6	5.0
" 12, "	6.1	5.4	" 20,1942	22.4	4.9
" 19, "	7.1	8.3	Sept.4,1933	23.1	5.2
" 26, "	10.0	6.9	" 20,1935	19.6	6.1
Mar. 3,1934	10.1	7.4	" 8,1937	20.1	6.0
" 6,1935	8.1	6.8	" 12,1939	19.2	4.8
" 12,1936	11.1	7.4	" 17,1940	18.7	4.4
" 20,1937	13.0	7.1	" 22,1941	18.0	4.6
" 16,1938	9.5	7.0	" 18,1942	18.4	5.2
" 7,1939	6.0	7.3	Oct. 6,1933	16.0	6.0
" 22,1940	15.0	6.1	" 3,1934	14.2	6.1
" 18,1941	12.0	6.1	" 20,1936	17.1	5.1
" 4,1942	8.5	7.1	" 4,1937	14.4	5.7
Apr. 6,1933	11.6	6.4	" 20,1938	16.3	6.7
" 18,1935	15.0	7.1	" 18,1940	15.0	7.1
" 20,1937	18.0	6.2	" 6,1941	17.0	6.1
" 16,1939	19.1	6.8	" 4,1942	16.0	7.0
" 12,1941	18.2	7.0	Nov.23,1931	13.2	7.2
May 6,1933	18.0	7.1	" 10,1932	10.6	8.0
" 5,1934	19.0	6.8	" 17,1933	8.1	8.2
" 12,1935	20.0	5.6	" 30,1934	12.1	7.9
" 14,1936	21.0	5.9	" 16,1935	9.6	7.2
" 7,1938	18.0	6.2	" 15,1936	10.0	6.1
" 3,1940	19.1	6.1	" 18,1937	8.6	7.2
" 15,1941	20.1	6.3	" 4,1938	11.0	6.2
" 17,1942	19.6	6.1	" 3,1939	12.6	5.1
June 4,1934	20.0	5.3	" 6,1940	8.4	7.0
" 6,1935	21.0	5.9	" 11,1941	9.9	6.2
" 12,1936	24.0	5.2	Dec.12,1931	7.0	8.1
" 17,1937	21.6	6.0	" 18,1932	7.1	8.0
" 19,1938	22.1	5.3	" 20,1933	6.0	8.2
" 27,1939	23.0	5.7	" 17,1934	5.6	6.1
" 6,1940	24.0	5.0	" 23,1935	4.1	7.1
" 7,1941	21.0	5.3	" 10,1936	5.6	8.3
			" 7,1937	6.0	6.9
			" 8,1938	7.1	7.4
			" 9,1939	6.2	6.5

DISSOLVED OXYGEN IN MISSOURI RIVER WATER
ST. CHARLES, MISSOURI, STATION

Data Assembled by Water Quality Laboratories
U.S.Fish & Wildlife Service, Columbia,Missouri

Date	Water Temperature °C.	Dissolved Oxygen Parts per Million	Date	Water Temperature °C.	Dissolved Oxygen Parts per Million
Jan.22,1934	6.0	7.0	July 10,1935	25.0	4.8
" 28,1936	6.1	7.0	" 14,1937	22.6	6.1
" 28,1938	5.4	6.6	" 22,1939	23.3	6.1
" 14,1940	7.4	7.1	" 8,1940	23.2	5.0
Feb. 8,1933	7.1	6.3	Aug. 8,1933	23.0	3.8
" 16,1935	8.1	6.0	" 8,1935	22.1	4.8
" 18,1936	6.0	6.8	" 11,1936	24.0	6.1
" 20,1937	5.0	6.0	" 20,1937	24.4	3.8
" 20,1938	5.8	6.4	" 8,1939	24.1	4.6
" 24,1939	6.0	7.2	Sept. 8,1933	24.0	4.8
" 10,1940	5.0	6.8	" 24,1935	21.0	5.8
Mar.14,1936	12.0	7.0	" 14,1939	18.8	5.1
" 24,1937	15.0	7.1	" 20,1940	18.9	4.8
" 18,1938	11.0	6.4	Oct.20,1935	14.9	5.8
" 10,1939	7.0	7.0	" 24,1938	15.0	6.0
Apr.19,1935	15.0	6.8	Nov.27,1932	9.8	7.8
" 24,1937	18.4	7.1	" 25,1935	9.4	7.0
" 20,1939	17.2	6.8	Dec.20,1932	6.8	7.4
May 8,1933	18.4	6.9	" 14,1936	5.9	8.0
" 8,1934	19.0	6.8	" 17,1937	6.0	6.8
" 14,1935	20.6	5.8	" 11,1939	5.8	6.0
" 20,1936	21.0	6.4			
" 10,1938	19.4	4.8			
" 8,1940	19.8	5.8			
June 8,1934	20.8	5.8			
" 9,1935	22.6	4.9			
" 14,1936	26.0	4.8			
" 18,1937	23.0	6.8			
" 23,1938	18.9	6.1			

MISSOURI RIVER INVESTIGATION

A P P E N D I X " C "

Mean Monthly Temperature of Water and of Air and Maximum Daily Temperatures of Water

Data from Water Works Records
and U.S. Weather Bureau
1943

Table 16 Missouri River Investigation - Mean Monthly Temper
and Maximum Daily Temperature of Water at Points

Locality	Year	Monthly Mean Temperatures of: (A) - A															
		January		February		March		April		May		June		July		Aug	
		(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	
Omaha, Nebr.	1928	30	38	32	38	43	44	47	49	65	66	67	62	77	81	76	
	1929	14	38	19	37	42	43	54	55	61	63	71	70	77	79	76	
Note: Water as delivered to mains at Omaha. Very little difference reported.	1930	14	38	41	40	39	44	56	56	62	63	72	73	83	80	77	
	1931	34	38	39	39	36	45	53	57	60	64	79	80	80	85	75	
	1932	21	37	31	36	31	41	54	57	65	65	74	75	79	81	75	
	1933	36	36	26	37	39	39	52	51	62	63	82	75	79	80	74	
	1934	30	34	30	34	37	36	55	49	73	66	79	75	85	81	79	
	1935	25	34	34	34	44	44	49	51	56	56	68	68	84	81	77	
	1936	10	33	7	33	42	37	49	45	68	64	74	73	87	83	82	
	1937	11	33	22	33	35	34	50	47	64	60	72	80	80	79	82	
	1938	25	36	29	34	45	40	53	49	61	61	73	72	80	79	79	
	1939	33	37	20	35	39	44	51	46	69	66	74	72	81	79	75	
	1940	8	34	25	33	36	35	50	49	61	59	73	72	80	78	73	
	1941	26	35	26	36	37	37	55	51	68	66	72	73	77	79	78	
Kansas City, Kans.	1938	32	34	38	38	52	48	56	52	65	65	74	74	82	80	83	
	1939	39	35	29	35	46	45	54	52	70	69	76	75	85	81	77	
	1940	13	32	33	33	43	39	54	53	64	64	75	75	82	82	76	
	1941	32	33	32	33	41	39	59	55	71	68	75	75	80	81	80	
	1942	32	33	32	34	45	41	61	54	64	63	74	75		80		
Kansas City, Mo.	1936									71	63	78	73	88	79	87	
	1937	23	40	31	45	40	52	54	51	67	63	76	73	81	80	84	
	1938	32	35	38	36	52	41	56	51	65	61	74	73	82	79	83	
	1939	39	40	29	37	46	40	54	50	70	68	76	76	85	80	77	
	1940	13	35	33	38	43	37	54	51	64	62	75	73	82	78	76	
	1941	32	33	32	33	41	38	59	55								
St. Louis, Mo.	1933	44	43	35	40	45	49	56	55	67	65	82	78	81	81	78	
	1934	38	38	31	36	41	42	57	55	71	69	83	80	87	83	80	
	1935	34	39	39	40	51	49	52	54	61	61	72	70	82	81	79	
	1936	25	36	24	33	49	46	52	54	71	71	77	75	87	82	86	
	1937	31	37	34	35	41	42	55	55	67	65	75	75	80	80	82	
	1938	33	35	42	42	54	51	58	56	66	65	74	74	82	82	82	
	1939	40	38	34	37	48	44	53	52	69	68	76	76	81	81	76	
	1940	17	33	34	34	44	41	55	55	64	63	76	75	80	79	78	
	1941	35	40	33	39	43	41	61	57	71	70	77	73	81	80	81	
	1942	33	36	34	39	47	46	60	58	66	67	75	78		84		

Note: Water temperatures (W) furnished by water works officials; Air temperatures

r Investigation - Mean Monthly Temperature of Water and of Air
ily Temperature of Water at Points on Lower Missouri River.

nthly Mean Temperatures of: (A)-Air (W)-Water																		Maximum Daily Temperature of Water	
April		May		June		July		August		September		October		November		December			
(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	(A)	(W)	July	August
47	49	65	66	67	62	77	81	76	82	64	71	56	62	41	47	31	39		83
54	55	61	63	71	70	77	79	76	80	64	70	55	62	34	44	28	39		84
56	56	62	63	72	73	83	80	77	84	69	75	54	60	44	49	31	38		91
53	57	60	64	79	80	80	85	75	80	74	75	59	64	45	51	37	41		90
54	57	65	65	74	75	79	81	75	79	65	72	53	58	37	42	24	37		84
52	51	62	63	82	75	79	80	74	75	72	72	54	56	42	43	31	37		81
55	49	73	66	79	75	85	81	79	77	62	65	61	61	44	46	25	37		84
49	51	56	56	68	68	84	81	77	79	67	69	51	54	36	40	27	35		85
49	45	68	64	74	73	87	83	82	79	70	73	52		38	40	29	34		89
50	47	64	60	72	80	80	79	82	80	69	72	53	56	36	43	27	37		83
53	49	61	61	73	72	80	79	79	78	70	72	63	62	39	45	31	39		81
51	46	69	66	74	72	81	79	75	75	72	70	55	54	42	42	34	40		81
50	49	61	59	73	72	80	78	73	77	69	71	61	61	35	44	31	35		82
55	51	68	66	72	73	77	79	78	79	69	71	55	58	40	42	33	37		85
56	52	65	65	74	74	82	80	83	80	72	72	66	63	45	45	36	36	85	84
54	52	70	69	76	75	85	81	77	77	77	74	62	60	44	47	39	40	87	82
54	53	64	64	75	75	82	82	76	78	70	73	65	62	41	44	37	37	90	86
59	55	71	68	75	75	80	81	80	81	72	73	60	61	46	43	40	38	87	88
61	54	64	63	74	75		80		79		66		58		44		32	85	85
		71	63	78	73	88	79	87	80	74	70	57	56	42	41	39	34	82	84
54	51	67	63	76	73	81	80	84	79	72	70	57	56	40	41	31	34	84	82
56	51	65	61	74	73	82	79	83	79	72	72	66	61	45	37	36	37	82	81
54	50	70	68	76	76	85	80	77	77	77	72	62	58	44	43	39	38	83	80
54	51	64	62	75	73	82	78	76	77	70	70	65	61	41	42	37	34	84	84
59	55																		
56	55	67	65	82	78	81	81	78	78	77	77	57	60	46	46	40	41	84	83
57	55	71	69	83	80	87	83	80	77	67	68	63	62	50	54	33	40	88	84
52	54	61	61	72	70	82	81	79	80	71	70	59	60	43	51	30	39	86	86
52	54	71	71	77	75	87	82	86	81	74	74	59	59	43	46	39	38	85	86
55	55	67	65	75	75	80	80	82	80	70	72	57	58	42	45	32	35	84	82
58	56	66	65	74	74	82	82	82	81	74	74	66	63	48	48	36	38	84	85
53	52	69	68	76	76	81	81	76	77	77	74	63	61	45	47	39	40	86	80
55	55	64	63	76	75	80	79	78	78	72	70	66	62	44	44	40	39	85	86
61	57	71	70	77	75	81	80	81	80	73	73	63	64	47	49	41	43	85	86
60	58	66	67	75	78		84		82		77		65		55		42	88	88

ter works officials; Air temperatures (A) from reports of U. S. Weather Bureau.